

INTERPOLATION PROCESSING APPARATUS AND RECORDING MEDIUM
HAVING INTERPOLATION PROCESSING PROGRAM RECORDED THEREIN

This application is a continuation of International
5 Application No. PCT/JP00/09040 filed December 20, 2000.

INCORPORATION BY REFERENCE

The disclosures of following applications are herein
incorporated by reference: Japanese Patent Application No.
10 H11-363007 filed December 21, 1999; Japanese Patent
Application No. 2000-204768 filed July 6, 2000; and
International Application No. PCT/JP00/09040 filed
December 20, 2000.

15 BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an interpolation
processing apparatus that engages in interpolation
processing on color image data to supplement a color
20 component and a luminance component missing in pixels and
a recording medium having an interpolation processing
program for achieving the interpolation processing on a
computer, that can be read by a computer.

25 2. Description of the Related Art

05877002-061404

Some electronic cameras generate color image data by employing an image-capturing sensor having three color (R, G and B: red, green and blue) color filters provided at specific positions (e.g., a Bayer array). In such an electronic camera in which the individual pixels at the image-capturing sensor each output color information corresponding to only a single color component, it is necessary to implement interpolation processing to obtain color information corresponding to all the color components for each pixel.

In an interpolation processing method proposed in the prior art, spatial similarity manifested by an interpolation target pixel undergoing the interpolation processing is judged and an interpolation value is calculated by using the color information output from pixels positioned along the direction in which a high degree of similarity is manifested.

For instance, in the art disclosed in USP No. 5,629,734, a green color interpolation value G5 for the interpolation target pixel is calculated through one formula among formula 1 through formula 3 when the color information corresponding to individual pixels is provided as shown below, with A5 representing the color information at the interpolation target pixel (a pixel with the green color component missing), A1, A3, A7 and A9 representing

color information from pixels provided with color filters
in the same color as the color of the filter at the
interpolation target pixel and G2, G4, G6 and G8
representing color information from pixels provided with
5 green color filters.

A1

G2

A3 G4 A5 G6 A7

G8

10 A9

If a marked similarity manifests along the horizontal
direction, the green color interpolation value G5 for the
interpolation target pixel is calculated through;

$$G5 = (G4 + G6) / 2 + (-A3 + 2A5 - A7) / 4 \quad \dots \text{ (formula 1) .}$$

15 If a marked similarity manifests along the vertical
direction, the green color interpolation value G5 for the
interpolation target pixel is calculated through;

$$G5 = (G2 + G8) / 2 + (-A1 + 2A5 - A9) / 4 \quad \dots \text{ (formula 2) .}$$

If roughly equal degrees of similarity manifest along the
20 horizontal direction and the vertical direction, the green
color interpolation value G5 for the interpolation target
pixel is calculated through

$$G5 = (G2 + G4 + G6 + G8) / 4 + (-A1 - A3 + 4A5 - A7 - A9) / 8 \quad \dots \text{ (formula 3) .}$$

It is to be noted that in order to simplify the subsequent
25 explanation, the first terms $((G4 + G6) / 2, (G2 + G8) / 2)$ in

formulae 1 and 2 are each referred to as a primary term and that second terms $((-A3 + 2A5 - A7)/4$, $(-A1 + 2A5 - A9)/4$) in formulae 1 and 2 are each referred to as a correctional term.

5 In USP No. 5,629,734, assuming that the image data undergoing the interpolation processing manifest marked similarity along the horizontal direction with A3, G4, A5, G6 and A7 provided as indicated with ● marks in FIG. 17, A4 representing the average of A3 and A5, and A6
10 representing the average of A5 and A7, the value of the correctional term in formula 1 is equivalent to the vector quantity (α in FIG. 17) representing the difference between A5 and the average of A4 and A6. In addition, the green color interpolation value G5 is equivalent to a
15 value achieved by correcting the average of the values indicated by the color information from pixels adjacent along the horizontal direction (corresponds to the value of the primary term in formula 1) by α .

In other words, in the art disclosed in USP No.
20 5,629,734, a green color interpolation value is calculated by assuming that the color difference between the green color component and the color component (the red color component or the blue color component) at the interpolation target pixel is constant $((A4-G4), (A5-G5)$
25 and $(A6-G6)$ in FIG. 17 match) and correcting the average

of the values indicated by the color information from the pixels that are adjacent along the direction in which a high degree of similarity is manifested with color information corresponding to the same color component as
5 that of the interpolation target pixel.

Optical systems such as lenses are known to manifest magnification chromatic aberration. For instance, if there is magnification chromatic aberration at the photographic lens of an electronic camera having an image-
10 capturing sensor provided with color filters in three colors, i.e., R, G and B, arranged in a Bayer array, images corresponding to the red color component and the blue color component are formed at positions slightly offset from the position at which the image corresponding
15 to the green color component is formed, as shown in FIGS. 18B and 18C.

If the photographic lens is free of any magnification chromatic aberration and color information corresponding to the individual pixels is provided as indicated by the ●
20 marks in FIG. 19A (the image data undergoing the interpolation processing manifest marked similarity along the horizontal direction, the color information corresponding to the green color component indicates a constant value and the values indicated by the color
25 information corresponding to the red color component and

the color information corresponding to the blue color component both change gently in the vicinity of the interpolation target pixel (the pixel at which A5 is present), the value of the correctional term in formula 1 is 0 and, as a result, the average of G4 and G6 (the primary term) is directly used as the green color interpolation value G5 without correction.

However, when A3, A5 and A7 each represent color information corresponding to the red color component and each set of color information corresponding to the red color component is offset by one pixel to the right due to a magnification chromatic aberration at the photographic lens, the color information from the individual pixels undergoes a change as shown in FIG. 19B. Consequently, the value of the correctional term in formula 1 is not 0 and the primary term is over-corrected (hereafter referred to as an "over-correction") in such a case, resulting in the green color interpolation value G5 that should be similar to the values indicated by G4 and G6 becoming larger than the G4 and G6 values (hereafter this phenomenon is referred to as an "overshoot"). If, on the other hand, A3, A5 and A7 each represent color information corresponding to the blue color component and each set of color information corresponding to the blue color component is offset by one pixel to the left due to a

magnification chromatic aberration, the color information from the individual pixels undergoes a change as shown in FIG. 19C. Thus, the value of the correctional term in formula 1 is not 0, resulting in the green color

5 interpolation value G5 that should be similar to the G4 and G6 values becoming smaller than those corresponding to G4 and G6 (hereafter this phenomenon is referred to as an "undershoot") through an over-correction.

In other words, the art disclosed in USP No.
10 5,629,734 poses a problem in that color artifacts occur in the color image obtained through the interpolation processing due to a magnification chromatic aberration.

An over correction also occurs at a color boundary where the color difference changes as well as when there
15 is a magnification chromatic aberration. For instance, the color information corresponding to the individual pixels is provided as indicated by the ● marks in FIGS. 20A and 20B (when the color information corresponding to the green color component is constant and the values
20 identified by the color information corresponding to the red color component or the blue color component change drastically near the interpolation target pixel (the pixel at which A5 is present)), the value of the correctional term in formula 1 is not 0 and, an overshoot or an
25 undershoot occurs due to an over correction with regard to

the green color interpolation value G5, which should be similar to the values indicated by G4 and G6.

Thus, in a color boundary where the color difference changes, a color artifact occurs as a result of

5 interpolation processing even if there is no magnification chromatic aberration. It is to be noted that such a color artifact as that described above may occur when calculating a red color interpolation value or a blue color interpolation value as well as when calculating a green color interpolation value.

SUMMARY OF THE INVENTION

15 An object of the present invention is to provide an interpolation processing apparatus capable of preventing occurrence of color artifacts and a recording medium having recorded therein an interpolation processing program with which occurrence of color artifacts can be prevented.

20 More specifically, an object of the present invention is to suppress the occurrence of color artifacts by reducing the problems of the prior art while retaining the advantages of the interpolation processing in the prior art and reducing the degree of the adverse effect of magnification chromatic aberration.

25 In order to achieve the object described above, a

first interpolation processing apparatus according to the present invention that engages in processing on image data which are provided in a colorimetric system constituted of first ~ nth ($n \geq 2$) color components and include color information corresponding to a single color component provided at each pixel to determine an interpolation value equivalent to color information corresponding to the first color component for a pixel at which the first color component is missing, comprises: an interpolation value calculation section that uses color information at pixels located in a local area containing an interpolation target pixel to undergo interpolation processing to calculate an interpolation value including, at least (1) local average information of the first color component with regard to the interpolation target pixel and (2) local curvature information corresponding to at least two color components with regard to the interpolation target pixel.

Namely, the first interpolation processing apparatus calculates an interpolation value by correcting the "local average information of the first color component with regard to the interpolation target pixel" with the "local curvature information corresponding to at least two color components with regard to the interpolation target pixel."

It is to be noted that in the explanation of the first interpolation processing apparatus, the "local

average information of the first color component with regard to the interpolation target pixel" may be the average of the values indicated by the color information corresponding to the first color component present in the local area containing the interpolation target pixel or a value within the range of the values indicated by the color information corresponding to the first color component in the local area containing the interpolation target pixel. In addition, the "local curvature information corresponding to at least two color components with regard to the interpolation target pixel" refers to information that indicates how the color information corresponding to at least two color components in the local area containing the interpolation target pixel changes. In other words, the local curvature information corresponding to a given color component is information that indicates the degree of change in the rate of change occurring with regard to the color component in the local area, and when the values corresponding to each color component are plotted and rendered as a curve (or a polygonal line), the information indicates the curvature and the degree of change in the curvature (this definition applies in the subsequent description). The information, which may be obtained by calculating a quadratic differential or a higher differential of the color

component, indicates a value reflecting structural information with regard to fluctuations in the values corresponding to the color component. When the information is rendered in a polygonal line, it indicates changes in the inclinations of the individual line segments.

A second interpolation processing apparatus achieves that in the first interpolation processing apparatus the interpolation value calculation section calculates, as the
10 local curvature information corresponding to at least two color components, (1) local curvature information based upon a color component matching a color component at the interpolation target pixel and (2) local curvature
information based upon a color component other than the
15 color component at the interpolation target pixel.

Namely, in the second interpolation processing apparatus, the interpolation value is calculated by correcting the "local average information of the first color component with regard to the interpolation target pixel" with the "local curvature information based upon a color component matching the color component at the interpolation target pixel" and the "local curvature information based upon a color component other than the color component at the interpolation target pixel."

25 It is to be noted that in the explanation of the

second interpolation processing apparatus, the "local curvature information based upon a color component matching the color component at the interpolation target pixel (or a color component other than the color component at the interpolation target pixel)" refers to information that indicates how the color information corresponding to the color component matching the color component at the interpolation target pixel (or a color component other than the color component at the interpolation target pixel) in the local area containing the interpolation target pixel changes and is represented as a value reflecting the structural information regarding the fluctuations obtained through calculation of a quadratic differential or a higher differential of the color component.

A third interpolation processing apparatus that engages in processing on image data which are provided in a colorimetric system constituted of first ~ nth ($n \geq 2$) color components and include color information corresponding to a single color component provided at each pixel to determine an interpolation value equivalent to color information corresponding to the first color component for a pixel at which the first color component is missing, comprises: an interpolation value calculation section that uses color information at pixels located in a

local area containing an interpolation target pixel to
undergo interpolation processing to calculate an
interpolation value including, at least (1) local average
information of the first color component with regard to
5 the interpolation target pixel and (2) local curvature
information based upon a color component other than a
color component at the interpolation target pixel.

Namely, in the third interpolation processing
apparatus, the interpolation value is calculated by
10 correcting the "local average information of the first
color component with regard to the interpolation target
pixel" with the "local curvature information based upon a
color component other than the color component at the
interpolation target pixel."

15 It is to be noted that in the explanation of the
third interpolation processing apparatus, the "local
curvature information based upon a color component other
than the color component at the interpolation target
pixel" refers to information that indicates how the color
20 information corresponding to the color component other
than the color component at the interpolation target pixel
in the local area containing the interpolation target
pixel changes and is represented as a value reflecting the
structural information regarding the fluctuations obtained
25 through calculation of a quadratic differential or a

higher differential of the color component.

A fourth interpolation processing apparatus that engages in processing on image data which are provided in a colorimetric system constituted of first ~ nth ($n \geq 2$) color components and include color information corresponding to a single color component provided at each pixel to determine an interpolation value equivalent to color information corresponding to the first color component for a pixel at which the first color component is missing, comprises: an interpolation value calculation section that uses color information at pixels located in a local area containing an interpolation target pixel to undergo interpolation processing to calculate an interpolation value including, at least (1) local average information of the first color component with regard to the interpolation target pixel and (2) local curvature information corresponding to the first color component with respect to the interpolation target pixel.

Namely, in the fourth interpolation processing apparatus, the interpolation value is calculated by correcting the "local average information of the first color component with regard to the interpolation target pixel" with the "local curvature information corresponding to the first color component with regard to the interpolation target pixel"

It is to be noted that in the explanation of the fourth interpolation processing apparatus, the "local curvature information corresponding to the first color component with respect to the interpolation target pixel" refers to information that indicates how the color information corresponding to the first color component in the local area containing the interpolation target pixel changes and is represented as a value reflecting the structural information regarding the fluctuations obtained through calculation of a quadratic differential or a higher differential of the color component.

A fifth interpolation processing apparatus achieves that in the first through third interpolation processing apparatus a first similarity judgment section that judges degrees of similarity to the interpolation target pixel along at least two directions in which pixels with color information corresponding to the first color component are connected with the interpolation target pixel; and a second similarity judgment section that judges degrees of similarity to the interpolation target pixel along at least two directions other than the directions in which the degrees of similarity are judged by the first similarity judgment section, are further provided, and: the interpolation value calculation section selects a direction along which pixels having color information to

be used to calculate the local average information of the first color component are set based upon results of a judgment made by the first similarity judgment section;

(1) the interpolation value calculation section selects a direction along which pixels having color information to be used to calculate the local curvature information are set based upon results of the judgment made by the first similarity judgment section if the local curvature information is "local curvature information constituted of a single color component and manifesting directionality along a direction in which degrees of similarity are judged by the first similarity judgment section"; and (2) the interpolation value calculation section selects a direction along which pixels having color information to be used to calculate the local curvature information are set based upon results of a judgment made by the second similarity judgment section if the local curvature information is "local curvature information constituted of a single color component and manifesting directionality along a direction in which degrees of similarity are judged by the second similarity judgment section."

Namely, in the fifth interpolation processing apparatus, any of the "local curvature information corresponding to at least two color components with regard to the interpolation target pixel" in the first

interpolation processing apparatus and the "local curvature information based upon a color component matching the color component at the interpolation target pixel" and the "local curvature information based upon a color component other than the color component at interpolation target pixel" in the second or the third interpolation processing apparatus that constitutes "local curvature information constituted of a single color component and manifesting directionality along a direction in which degrees of similarity are judged by the first similarity judgment section" is calculated by using color information at pixels present along a direction selected based upon the results of the judgment made by the first similarity judgment section, whereas any of the information listed above that constitutes "local curvature information constituted of a single color component and manifesting directionality along a direction in which degrees of similarity are judged by the second similarity judgment section" is calculated by using color information at pixels present along a direction selected based upon the results of the judgment made by the second similarity judgment section.

It is to be noted that the details of the directions along which the various types of local curvature information manifest directionality are to be defined in

the "Best Mode For Carrying Out The Invention".

As described above, the color information used to calculate local curvature information can be selected in correspondence to degrees of similarity to the interpolation target pixel in the fifth interpolation processing apparatus. In addition, the color information used to calculate the local average information of the first color component, too, can be selected in correspondence to the degrees of similarity to the interpolation target pixel.

A sixth interpolation processing apparatus that engages in processing on image data which are provided in a colorimetric system constituted of first ~ nth ($n \geq 2$) color components and include color information corresponding to a single color component provided at each pixel to determine an interpolation value equivalent to color information corresponding to the first color component for a pixel at which the first color component is missing, comprises: an interpolation value calculation section that calculates an interpolation value including at least two terms, i.e., a first term and a second term by using color information at pixels set in a local area containing an interpolation target pixel to undergo interpolation processing; a first similarity judgement section that judges degrees of similarity to the

interpolation target pixel along at least two directions
in which pixels having color information corresponding to
the first color component are connected to the
interpolation target pixel; and a second similarity

5 judgment section that judges degrees of similarity to the
interpolation target pixel along at least two directions
other than the directions in which the degrees of

similarity are judged by the first similarity judgment
section, wherein: the interpolation value calculation
10 section selects a direction along which pixels having
color information to be used to calculate the first term
are set based upon results of a judgment made by the first
similarity judgment section and selects a direction along
which pixels having color information to be used to
15 calculate the second term are set based upon results of a
judgment made by the second similarity judgment section.

Namely, in the sixth interpolation processing
apparatus, in which the directions in which similarity is
judged by the second similarity judgment section are
20 different from the directions along which similarity is
judged by the first similarity judgment section, the
processing can be performed by using color information
from pixels set along more directions including the
direction along which color information used to calculate
25 the second term is provided as well as the direction along

which color information used to calculate the first term is provided.

Thus, the interpolation value can be calculated by using color information at pixels located along a finely differentiated plurality of directions in the sixth interpolation processing apparatus. In addition, the first term and the second term can be calculated by using color information at pixels set along the direction in which a high degree of similarity is manifested or through weighted synthesis of color information from pixels located along a plurality of directions, which is performed in correspondence to varying degrees of similarity, in the sixth interpolation processing apparatus.

A seventh interpolation processing apparatus achieves that in the sixth interpolation processing apparatus the interpolation value calculation section: calculates a term containing (a) local average information of the first color component with regard to the interpolation target pixel and (b) local curvature information constituted of a single color component and manifesting directionality along a direction in which degrees of similarity are judged by the first similarity judgment section, as the first term; and calculates a term containing local curvature information constituted of a single color

component and manifesting directionality along a direction in which degrees of similarity are judged by the second similarity judgment section, as the second term.

Namely, in the seventh interpolation processing apparatus, the interpolation value is calculated by correcting the "local average information of the first color component with regard to the interpolation target pixel" with the "local curvature information constituted of a single color component and manifesting directionality along a direction in which degrees of similarity are judged by the first similarity judgment section" and the "local curvature information constituted of a single color component and manifesting directionality along a direction in which degrees of similarity are judged by the second similarity judgment section."

It is to be noted that the details of the directions along which the various types of local curvature information manifest directionality are to be defined in the "Best Mode For Carrying Out The Invention".

An eighth interpolation processing apparatus achieves that in the fifth or seventh interpolation processing apparatus: when image data are provided in a colorimetric system constituted of first ~ third color components with the first color component achieving a higher spatial frequency than the second color component and the third

color component, the first color component set in a checker-board pattern, the second color component and the third color component each set in a line sequence between pixels at which color information corresponding to the

5 first color component is present and information corresponding to the second color component present at the interpolation target pixel; the first similarity judgment section calculates similarity degrees manifested by the interpolation target pixel along two directions, i.e., a

10 vertical direction and a horizontal direction, in which pixels with color information corresponding to the first color component that are closest to the interpolation target pixel are connected to the interpolation target pixel and makes a judgment with regard to degrees of

15 similarity manifested by the interpolation target pixel along the vertical direction and the horizontal direction based upon a difference between the similarity degrees; the second similarity judgment section calculates similarity degrees manifested by the interpolation target

20 pixel along two diagonal directions in which pixels with color information corresponding to the third color component that are closest to the interpolation target pixel are connected to the interpolation target pixel and makes a judgment with regard to degrees of similarity

25 manifested by the interpolation target pixel along the two

diagonal directions based upon a difference between the similarity degrees; and the interpolation value calculation section selects at least either the second color component or the first color component based upon which the "local curvature information constituted of a single color component and manifesting directionality along a direction in which degrees of similarity are judged by the first similarity judgment section" is provided and selects at least either the second color component or the third color component based upon which the "local curvature information constituted of a single color component and manifesting directionality along a direction in which degrees of similarity are judged by the second similarity judgment section" is provided.

The details of the directions along which the various types of local curvature information manifest directionality are to be defined in the "Best Mode For Carrying Out The Invention".

In the eighth interpolation processing apparatus, the color component manifesting directionality along the two directions, i.e., the vertical direction and the horizontal direction in which degrees of similarity are judged by the first similarity judgment section, includes the second color component and the first color component and the color components manifesting directionality along

the two diagonal directions in which degrees of similarity are judged by the second similarity judgment section includes the second color component and the third color component.

5 Thus, the "local curvature information constituted of a single color component and manifesting directionality along a direction in which degrees of similarity are judged by the first similarity judgment section" in the fifth or seventh interpolation processing apparatus is
10 calculated with respect to at least either the second color component or the first color component based upon the results of the judgment made by the first similarity judgment section and the "local curvature information constituted of a single color component and manifesting
15 directionality along a direction in which degrees of similarity are judged by the second similarity judgment section" is calculated with respect to at least either the second color component or the third color component based upon the results of the judgment made by the second
20 similarity judgment section.

 In addition, in the eighth interpolation processing apparatus, the similarity manifesting along the diagonal directions is reflected with a high degree of reliability when calculating the "local curvature information based
25 upon a color component achieving similarity along a

direction in which degrees of similarity are judged by the second similarity judgment section."

A ninth interpolation processing apparatus achieves that in the eighth interpolation processing apparatus:

5 when the local curvature information is "local curvature information based upon a color component other than the color component at the interpolation target pixel", the interpolation value calculation section selects the first color component or the third color component to which the
10 local curvature information is to correspond in conformance to the degrees of similarity judged by the second similarity judgment section.

In the ninth interpolation processing apparatus, the third color component is present at pixels adjacent to the
15 interpolation target pixel along the two diagonal directions and the similarity judged by the second similarity judgment section is the similarity manifested by the interpolation target pixel along the two diagonal directions.

20 In other words, in the ninth interpolation processing apparatus, the similarity along the diagonal directions can be reflected in the "local curvature information based upon a color component other than the color component at the interpolation target pixel" by switching the "local
25 curvature information based upon a color component other

direction and the horizontal direction if a difference between the similarity degrees along the vertical direction and the horizontal direction is smaller than a specific threshold value; and the second similarity judgment section judges that roughly equal degrees of similarity manifest along the two diagonal directions if a difference between the similarity degrees along the two diagonal directions is smaller than a specific threshold value.

As a result, the adverse effect of noise can be reduced in the judgement of the similarity along the two directions, i.e., the vertical direction and the horizontal direction and the similarity manifesting along the two diagonal directions in the 11th interpolation processing apparatus.

A 12th interpolation processing apparatus achieves that in the eighth interpolation processing apparatus: the first similarity judgment section calculates the similarity degrees along the vertical direction and the horizontal direction by using color information corresponding to a plurality of color components for a single interpolation target pixel; and the second similarity judgment section calculates the similarity degrees along the two diagonal directions by using color information corresponding to a plurality of color

components for a single interpolation target pixel.

In other words, in the 12th interpolation processing apparatus, color information corresponding to a plurality of color components is reflected in the judgement of the
5 similarity manifesting along the vertical and horizontal directions and the similarity manifesting along the two diagonal directions.

A 13th interpolation processing apparatus achieves that in the twelfth interpolation processing apparatus:
10 the second similarity judgment section calculates a similarity degree manifesting along each of the two diagonal directions through weighted addition of: (1) a similarity degree component constituted of color information corresponding to the first color component
15 alone; (2) a similarity degree component constituted of color information corresponding to the second color component alone; (3) a similarity degree component constituted of color information corresponding to the third color component alone; and (4) a similarity degree
20 component constituted of color information corresponding to the second color component and the third color component.

As a result, color information corresponding to a plurality of color components is reflected with a high
25 degree of reliability in the judgement of the similarity

manifesting along the two diagonal directions in the 13th interpolation processing apparatus.

A 14th interpolation processing apparatus achieves that in the eighth: the first similarity judgment section
5 calculates similarity degrees along the vertical direction and the horizontal direction for each pixel and makes a judgment on similarity manifested by the interpolation target pixel along the vertical direction and the horizontal direction based upon differences in similarity
10 degrees manifesting at nearby pixels as well as at the interpolation target pixel; and the second similarity judgment section calculates similarity degrees along the two diagonal directions for each pixel and makes a judgment on similarity manifested by the interpolation
15 target pixel along the two diagonal directions based upon differences in similarity degrees manifesting at nearby pixels as well as at the interpolation target pixel.

Namely, in the 14th interpolation processing apparatus, the continuity with the nearby pixels is
20 reflected in the judgement of the similarity manifesting along the vertical and horizontal directions and the similarity manifesting along the two diagonal directions.

A 15th interpolation processing apparatus that engages in processing on image data which are provided in
25 a colorimetric system constituted of first ~ nth ($n \geq 2$)

09877002 "061101

color components and include color information
corresponding to a single color component provided at each
pixel to determine an interpolation value equivalent to
color information corresponding to the first color
5 component for a pixel at which the first color component
is missing, comprises: a first term calculation section
that calculates a first term representing average
information of the first color component with regard to an
interpolation target pixel to undergo interpolation
10 processing by using color information corresponding to
color components at pixels set in a local area containing
the interpolation target pixel; a second term calculation
section that calculates a second term representing local
curvature information based upon a color component
15 matching the color component at the interpolation target
pixel with regard to the interpolation target pixel by
using color information corresponding to color components
at pixels set in a local area containing the interpolation
target pixel; and an interpolation value calculation
20 section that calculates an interpolation value by adding
the second term multiplied by a weighting coefficient
constituted of color information corresponding to a
plurality of color components at pixels in the local area
containing the interpolation target pixel to the first
25 term.

In other words, in the 15th interpolation processing apparatus, the interpolation value is calculated by correcting the "average information of the first color component with regard to the interpolation target pixel" with the "local curvature information based upon a color component matching the color component at the interpolation target pixel with regard to the interpolation target pixel" multiplied by a weighting coefficient constituted of color information corresponding to a plurality of color components present at pixels within a local area containing the interpolation target pixel.

A 16th interpolation processing apparatus achieves that in the 15th interpolation processing apparatus: the interpolation value calculation section uses color information corresponding to a plurality of color components provided at the interpolation target pixel and at a plurality of pixels set along a predetermined direction relative to the interpolation target pixel to ascertain inclinations manifesting in color information corresponding to the individual color components along the direction and calculates the weighting coefficient in conformance to a correlation manifesting among the inclinations in the color information corresponding to the individual color components.

As a result, in the 16th interpolation processing apparatus, in which the "average information of the first color component with regard to the interpolation target pixel" is corrected with the "local curvature information based upon a color component matching the color component at the interpolation target pixel with regard to the interpolation target pixel" multiplied by the weighting coefficient, and the weighting coefficient is calculated in conformance to the correlation among the inclinations of the color information corresponding to the different color components in the local area containing the interpolation target pixel.

A 17th interpolation processing apparatus that implements processing for supplementing a color component value at a pixel at which information corresponding to a color component is missing in image data provided in a colorimetric system constituted of a luminance component and the color component, with the luminance component having a higher spatial frequency than the color component and the luminance component present both at pixels having information corresponding to the color component and at pixels lacking information corresponding to the color component, comprises: a hue value calculation section that calculates hue values at a plurality of pixels located near an interpolation target pixel to undergo

interpolation processing and having both the luminance component and the color component by using luminance component values and color component values at the individual pixels; a hue value interpolation section that
5 calculates a hue value at the interpolation target pixel by using a median of the hue values at the plurality of pixels calculated by the hue value calculation section; and a color conversion section that interpolates a color component at the interpolation target pixel by using the
10 luminance component at the interpolation target pixel to convert the hue value at the interpolation target pixel calculated by the hue value interpolation section to a color component.

Namely, in the 17th interpolation processing
15 apparatus, the hue value of the interpolation target pixel is calculated by using the median of the hue values of a plurality of pixels located near the interpolation target pixel.

A 18th interpolation processing apparatus that
20 implements processing for supplementing a luminance component at a pixel at which information corresponding to a luminance component is missing and supplementing a color component at a pixel at which information corresponding to a color component is missing, on image data provided in a
25 colorimetric system constituted of the luminance component

and the color component, with the luminance component having a higher spatial frequency than the color component and a given pixel having only information corresponding to either the luminance component or the color component,

5 comprises: a luminance component interpolation section that interpolates a luminance component at a luminance component interpolation target pixel to undergo luminance component interpolation processing by using at least either "similarity manifesting between the luminance component interpolation target pixel and a pixel near the

10 luminance component interpolation target pixel" or "a plurality of color components within a local area containing the luminance component interpolation target pixel"; a hue value calculation section that calculates

15 hue values at a plurality of pixels located near an interpolation target pixel to undergo color component interpolation processing, having color component values and having luminance component values interpolated by the luminance component interpolation section, by using the

20 luminance component values and color component values at the individual pixels; a hue value interpolation section that calculates a hue value for the interpolation target pixel by using a median of the hue values at the plurality of pixels calculated by the hue value calculation section;

25 and a color conversion section that interpolates a color

component value for the interpolation target pixel by
using the luminance component value at the interpolation
target pixel to convert the hue value at the interpolation
target pixel calculated by the hue value interpolation
5 section to a color component value.

Namely, in the 18th interpolation processing
apparatus, the hue value of the interpolation target pixel
is calculated by using the median of the hue values of a
plurality of pixels located near the interpolation target
10 pixel.

A 19th interpolation processing apparatus achieves
that in the 17th or 18th interpolation processing
apparatus: when the luminance component in the image data
corresponds to a green color component and the color
15 component in the image data corresponds to a red color
component and a blue color component, the hue value
interpolation section calculates a hue value for the
interpolation target pixel by using a median of hue values
containing the red color component at pixels near the
20 interpolation target pixel if the green color component is
present but the red color component is missing at the
interpolation target pixel and calculates a hue value for
the interpolation target pixel by using a median of hue
values containing the blue color component at pixels near
25 the interpolation target pixel if the green color

component is present but the blue color component is missing at the interpolation target pixel.

In other words, in the 19th interpolation processing apparatus, the hue value of the interpolation target pixel at which the green color component is present but the red color component is missing is calculated by using the median of the hue values containing the red color component from pixels located near the interpolation target pixel, whereas the hue value of the interpolation target pixel at which the green color component is present but the blue color component is missing is calculated by using the median of the hue values containing the blue color component from pixels located near the interpolation target pixel.

A 20th interpolation processing apparatus achieves that in the 17th or 18th interpolation processing apparatus: when the luminance component in the image data corresponds to a green color component and the color component in the image data corresponds to a red color component and a blue color component, the hue value interpolation section calculates a hue value for the interpolation target pixel by using a median of hue values containing the red color component at pixels set near the interpolation target pixel if the blue color component is present but the red color component is missing at the

interpolation target pixel.

Namely, in the 20th interpolation processing apparatus, the hue value of the interpolation target pixel at which the blue color component is present but the red color component is missing is calculated by using the median of the hue values containing the red color component from pixels located near the interpolation target pixel.

A 21st interpolation processing apparatus achieves that in the 17th or 18th interpolation processing apparatus: when the luminance component in the image data corresponds to a green color component and the color component in the image data corresponds to a red color component and a blue color component, the hue value interpolation section calculates a hue value for the interpolation target pixel by using a median of hue values containing the blue color component at pixels set near the interpolation target pixel if the red color component is present but the blue color component is missing at the interpolation target pixel.

Namely, in the 21st interpolation processing apparatus, the hue value of the interpolation target pixel at which the red color component is present but the blue color component is missing is calculated by using the median of the hue values containing the blue color

component from pixels located near the interpolation target pixel.

000770000 0001001

A 22nd interpolation processing apparatus achieves that in the any one of the 17th through 21st interpolation processing apparatus a color component is missing at the interpolation target pixel present at only one pixel among four pixels set symmetrically along the vertical direction and the horizontal direction, and the hue value interpolation section comprises: a first hue value interpolation unit that calculates a hue value for the interpolation target pixel by using a median of hue values at a plurality of diagonally adjacent pixels if the hue values of the plurality of diagonally adjacent pixels adjacent to the interpolation target pixel along diagonal directions have been calculated by the hue value calculation section; and a second hue value interpolation unit that calculates a hue value for the interpolation target pixel by using a median of hue values at a plurality of vertically and horizontally adjacent pixels if the hue values of the plurality of vertically and horizontally adjacent pixels adjacent to the interpolation target pixel in the vertical direction and the horizontal direction have been calculated by the hue value calculation section or the first hue value interpolation unit.

to the interpolation target pixel, is calculated by using color information provided at pixels set within a local area containing the interpolation target pixel.

Namely, through the interpolation processing program
5 recorded at the first recording medium, the interpolation value is calculated by correcting the "local average information of the first color component with regard to the interpolation target pixel" with the "local curvature information corresponding to at least two color components
10 with regard to the interpolation target pixel."

A second recording medium has an interpolation processing program recorded therein to implement on a computer processing for determining an interpolation value equivalent to color information corresponding to a first
15 color component missing at a pixel, on image data provided in a colorimetric system constituted of first ~ nth ($n \geq 2$) color components with color information corresponding to a single color component present at each pixel. The interpolation processing program comprises: an
20 interpolation value calculation step in which an interpolation value including, at least (1) local average information of the first color component with regard to an interpolation target pixel to undergo the interpolation processing; and (2) local curvature information based upon
25 a color component other than a color component at the

interpolation target pixel, is calculated by using color information provided at pixels set within a local area containing the interpolation target pixel.

Namely, through the interpolation processing program
5 recorded at the second recording medium, the interpolation value is calculated by correcting the "local average information of the first color component with regard to the interpolation target pixel" with the "local curvature information based upon a color component other than the
10 color component at the interpolation target pixel."

A third recording medium has an interpolation processing program recorded therein to implement on a computer processing for determining an interpolation value equivalent to color information corresponding to a first
15 color component missing at a pixel, on image data provided in a colorimetric system constituted of first ~ nth ($n \geq 2$) color components with color information corresponding to a single color component present at each pixel. The interpolation processing program comprises: an
20 interpolation value calculation step in which an interpolation value including, at least (1) local average information of the first color component with regard to an interpolation target pixel to undergo the interpolation processing, and (2) local curvature information
25 corresponding to the first color component with respect to

the interpolation target pixel, is calculated by using color information provided at pixels set within a local area containing the interpolation target pixel.

Namely, through the interpolation processing program
5 recorded at the third recording medium, the interpolation value is calculated by correcting the "local average information of the first color component with regard to the interpolation target pixel" with the "local curvature information corresponding to the first color component
10 with respect to the interpolation target pixel."

A fourth recording medium has an interpolation processing program recorded therein to implement on a computer processing for determining an interpolation value equivalent to color information corresponding to a first
15 color component missing at a pixel, on image data provided in a colorimetric system constituted of first ~ nth ($n \geq 2$) color components with color information corresponding to a single color component present at each pixel. The interpolation processing program comprises: an
20 interpolation value calculation step in which an interpolation value including at least two terms, i.e., a first term and a second term is calculated by using color information at pixels set within a local area containing an interpolation target pixel to undergo interpolation
25 processing; a first similarity judgment step in which

degrees of similarity to the interpolation target pixel are judged along at least two directions in which pixels having color information corresponding to the first color component are connected with the interpolation target
5 pixel; and a second similarity judgment step in which degrees of similarity to the interpolation target pixel are judged along at least two directions other than the directions along which the degrees of similarity are judged in the first similarity judgment step, wherein: in
10 the interpolation value calculation step, a direction in which pixels having color information to be used to calculate the first term are set is selected based upon results of a judgment made in the first similarity judgment step and a direction in which pixels having color
15 information to be used to calculate the second term are set is selected based upon results of a judgment made in the second similarity judgment step.

In other words, since the directions along which similarity is judged in the second similarity judging step
20 are different from the directions in which similarity is judged in the first similarity judging step in the interpolation processing program recorded at the fourth recording medium, color information from pixels located along more diverse directions including a direction along
25 which the color information used to calculate the second

term is provided as well as a direction along which the color information used to calculate the first term is provided can be used in the processing.

USPTO
09/000,000
001,001

A fifth recording medium has an interpolation
5 processing program recorded therein to implement on a computer processing for determining an interpolation value equivalent to color information corresponding to a first color component missing at a pixel, on image data provided in a colorimetric system constituted of first ~ nth ($n \geq$
10 2) color components with color information corresponding to a single color component present at each pixel. The interpolation processing program comprises: a first term calculation step in which a first term representing average information of the first color component with
15 regard to an interpolation target pixel to undergo interpolation processing is calculated by using color information corresponding to a color component at pixels set within a local area containing the interpolation target pixel; a second term calculation step in which a
20 second term representing local curvature information based upon a color component matching the color component at the interpolation target pixel is calculated with regard to the interpolation target pixel by using color information corresponding to a color component at pixels set within a
25 local area containing the interpolation target pixel; and

an interpolation value calculation step in which an interpolation value is calculated by adding the second term multiplied by a weighting coefficient constituted of color information corresponding to a plurality of color components provided at pixels set within a local area containing the interpolation target pixel to the first term.

09876543210
10 Namely, through the interpolation processing program recorded at the fifth recording medium, the interpolation value is calculated by correcting the "average information of the first color component with regard to the interpolation target pixel" with the "local curvature information based upon a color component matching the color component at the interpolation target pixel with regard to the interpolation target pixel" multiplied by a weighting coefficient constituted of color information corresponding to a plurality of color components at the interpolation target pixel and at pixels located in the local area containing the interpolation target pixel.

20 A sixth recording medium has an interpolation processing program recorded therein for implementing on a computer processing supplementing a color component value at a pixel at which information corresponding to a color component is missing, on image data provided in a
25 colorimetric system constituted of a luminance component

and the color component, with the luminance component
having a higher spatial frequency than the color component
and the luminance component present both at pixels having
information corresponding to the color component and at
5 pixels lacking information corresponding to the color
component. The interpolation processing program
comprises: a hue value calculation step in which hue
values for a plurality of pixels near an interpolation
target pixel to undergo interpolation processing and
10 having information corresponding to both the luminance
component and the color component are calculated by using
luminance component values and color component values at
the individual pixels; a hue value interpolation step in
which a hue value for the interpolation target pixel is
15 calculated by using a median of the hue values at the
plurality of pixels calculated in the hue value
calculation step; and a color conversion step in which a
color component value at the interpolation target pixel is
interpolated by using a value indicated by the luminance
20 component present at the interpolation target pixel to
convert the hue value of the interpolation target pixel
calculated in the hue value interpolation step to a color
component value.

Namely, through the interpolation processing program
25 recorded at the sixth recording medium, the hue value of

the interpolation target pixel is calculated by using the median of the hue values at a plurality of pixels present near the interpolation target pixel.

A seventh recording medium has an interpolation
5 processing program recorded therein for implementing on a computer processing for supplementing a luminance component value at a pixel at which information corresponding to a luminance component is missing and a color component value at a pixel at which information
10 corresponding to a color component missing, on image data provided in a colorimetric system constituted of the luminance component and the color component, with the luminance component having a higher spatial frequency than the color component and information corresponding to
15 either the luminance component or the color component present at each pixel. The interpolation processing program comprises: a luminance component interpolation step in which a luminance component value is interpolated for a luminance component interpolation target pixel to
20 undergo luminance component interpolation processing by using at least either "similarity between the luminance component interpolation target pixel and a pixel near the luminance component interpolation target pixel" or "information corresponding to a plurality of color
25 components within a local area containing the luminance

component interpolation target pixel"; a hue value calculation step in which hue values at a plurality of pixels located near an interpolation target pixel to undergo color component interpolation processing, having
5 color component values and having luminance component values interpolated in the luminance component interpolation step are calculated by using the luminance component values and color component values at the individual pixels; a hue value interpolation step in which
10 a hue value for the interpolation target pixel is calculated by using a median of the hue values at the plurality of pixels calculated in the hue value calculation step; and a color conversion step in which a color component value is interpolated for the
15 interpolation target pixel by using the luminance component value at the interpolation target pixel to convert the hue value at the interpolation target pixel calculated in the hue value interpolation step to a color component value.

20 Namely, through the interpolation processing program recorded at the seventh recording medium, the hue value of the interpolation target pixel is calculated by using the median of the hue values at a plurality of pixels present near the interpolation target pixel.

25 It is to be noted that by adopting the interpolation

processing programs at the first ~ seventh recording media,
the first, third, fourth, sixth, 15th, 17th and 19th
interpolation processing apparatuses may be realized on a
computer. Likewise, the second, fifth, seventh ~ 14th,
5 16th, 18th, and 20th ~ 22nd interpolation processing
apparatuses may be realized through interpolation
processing programs recorded at recording media. These
interpolation processing programs may be provided to a
computer through a communication line such as the Internet.

10

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a functional block diagram of an electronic
camera corresponding to first through fifth embodiments;

15 FIGS. 2A and 2B show the arrangements of the color
components in the image data adopted in the first
embodiment, the second embodiment and the fourth
embodiment;

20 FIGS. 3A and 3B show the arrangements of the color
components in the image data adopted in the third
embodiment and the fifth embodiment;

FIG. 4 is a flowchart (1) of the operation achieved
at the interpolation processing unit in the first
embodiment;

25 FIG. 5 is a flowchart (2) of the operation achieved
at the interpolation processing unit in the first.

embodiment;

FIGS. 6A and 6B illustrate methods of weighted addition of similarity degree components;

FIG. 7 shows the directions along which marked
5 similarity manifests in correspondence to values $(HV[i,j], DN[i,j])$;

FIG. 8 shows the positions of the color information used to calculate the green color interpolation value $G[i,j]$;

10 FIGS. 9A and 9B show how the adverse effect of magnification chromatic aberration is eliminated;

FIGS. 10A ~ 10C illustrate median processing of the prior art;

FIGS. 11A and 11B illustrate the median processing
15 operation achieved in the first embodiment;

FIGS. 12A and 12B illustrate the ranges of the median processing implemented in the first embodiment;

FIG. 13 shows the positions of the color information used to calculate local curvature information;

20 FIG. 14 (continued from FIG. 13) shows the positions of the color information used to calculate local curvature information;

FIG. 15 illustrates the function of the weighting coefficient in the fourth embodiment;

25 FIG. 16 is a functional block diagram of a sixth

embodiment;

FIG. 17 illustrates an example of the interpolation processing in the prior art;

FIGS. 18A ~ 18C illustrate the adverse effects of magnification chromatic aberration;

FIGS. 19A ~ 19C illustrate over correction occurring due to magnification chromatic aberration; and

FIGS. 20A and 20B illustrate the effects of over correction occurring at a color boundary.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following is a detailed explanation of the embodiments of the present invention, given in reference to the drawings. FIG. 1 is a functional block diagram of the electronic camera corresponding to the first through fifth embodiments.

In FIG. 1, an electronic camera 10 comprises a control unit 11, a photographic optical system 12, an image-capturing unit 13, an A/D conversion unit 14, an image processing unit 15 and a recording unit 16. The image processing unit 15 is provided with an interpolation processing unit (e.g., a one-chip microprocessor dedicated to interpolation processing). The image-capturing unit 13 is provided with an image-capturing sensor (not shown) constituted by arranging R, G and B color filters in a

Bayer array.

It is to be noted that while FIG. 1 shows only the interpolation processing unit 17 in the image processing unit 15 to simplify the illustration, a functional block that engages in other image processing such as gradation conversion processing may also be provided in the image processing unit 15.

In FIG. 1, the control unit 11 is connected to the image-capturing unit 13, the A/D conversion unit 14, the image processing unit 15 and the recording unit 16. In addition, an optical image obtained at the photographic optical system 12 is formed at the image-capturing sensor in the image-capturing unit 13. An output from the image-capturing unit 13 is quantized at the A/D conversion unit 14 and is provided to the image processing unit 15 as image data. The image data provided to the image processing unit 15 undergo interpolation processing at the interpolation processing unit 17 and after having undergone image compression as necessary, they are recorded via the recording unit 16. The image data with the degrees of resolution corresponding to the individual color components improved through the interpolation processing are ultimately output as image data in a colorimetric system that corresponds to the type of device that is connected, such as a display or a printer.

interpolation values for pixels at which the green color component is missing (hereafter referred to as "G interpolation processing") and then engages in interpolation processing through which red color interpolation values and blue color interpolation values are supplemented at pixels at which the red color component and the blue color component are missing (hereafter referred to as "RB interpolation processing"). However, since the interpolation processing implemented to supplement blue color interpolation values (hereafter referred to as "B interpolation processing") is implemented in a manner identical to the manner with which the interpolation processing for supplementing red color interpolation values (hereafter referred to as "R interpolation processing ") is implemented, its explanation is omitted.

In addition, it is assumed that the pixel at coordinates $[i,j]$ is the interpolation target pixel to undergo the G interpolation processing, to simplify the subsequent explanation. Since the green color interpolation value can be calculated through the G interpolation processing in each of the embodiments explained below regardless of the color component (red or blue) at the interpolation target pixel, R and B in FIGS. 2A and 2B and FIGS. 3A and 3B are all replaced with Z with

the color information at the interpolation target pixel expressed as $Z[i,j]$ and color information at other pixels also expressed in a similar manner in the following explanation.

5 (First Embodiment)

FIGS. 4 and 5 present a flowchart of the operation achieved in the interpolation processing unit 17 in the first embodiment, with FIG. 4 corresponding to the operation of the interpolation processing unit 17 during the G interpolation processing and FIG. 5 corresponding to the operation of the interpolation processing unit 17 during the R interpolation processing.

The explanation of the operation achieved in the first embodiment given below focuses on the operation of the interpolation processing unit 17 by referring to FIGS. 4 and 5.

First, the interpolation processing unit 17 calculates a similarity degree $C_v[i,j]$ along the vertical direction and a similarity degree $C_h[i,j]$ along the horizontal direction for an interpolation target pixel at which the green component is missing (FIG. 4 S1).

Now, the details of the processing implemented to calculate the vertical similarity degree $C_v[i,j]$ and the horizontal similarity degree $C_h[i,j]$ in the first embodiment are explained.

The interpolation processing unit 17 first calculates a plurality of types of similarity degree components along the vertical direction and the horizontal direction defined through the following formulae 10 ~ 21.

5 G-G similarity degree component along vertical
direction: $Cv1[i,j]=|G[i,j-1]-G[i,j+1]|$... formula 10

 G-G similarity degree component along horizontal
direction: $Ch1[i,j]=|G[i-1,j]-G[i+1,j]|$... formula 11

 B-B (R-R) similarity degree component along vertical
10 direction: $Cv2[i,j]=(|Z[i-1,j-1]-Z[i-1,j+1]|+|Z[i+1,j-1]-Z[i+1,j+1]|)/2$... formula 12

 B-B (R-R) similarity degree component along
horizontal direction: $Ch2[i,j]=(|Z[i-1,j-1]-Z[i+1,j-1]|+|Z[i-1,j+1]-Z[i+1,j+1]|)/2$... formula 13

15 R-R (B-B) similarity degree component along vertical
direction: $Cv3[i,j]=(|Z[i,j-2]-Z[i,j]|+|Z[i,j+2]-Z[i,j]|)/2$... formula 14

 R-R (B-B) similarity degree component along
horizontal direction: $Ch3[i,j]=(|Z[i-2,j]-Z[i,j]|+|Z[i+2,j]-Z[i,j]|)/2$... formula 15

 G-R (G-B) similarity degree component along vertical
direction: $Cv4[i,j]=(|G[i,j-1]-Z[i,j]|+|G[i,j+1]-Z[i,j]|)/2$... formula 16

 G-R (G-B) similarity degree component along
25 horizontal direction: $Ch4[i,j]=(|G[i-1,j]-$

09670002-0001001

$|Z[i,j]| + |G[i+1,j] - Z[i,j]|) / 2 \cdots \text{formula 17}$

B-G (R-G) similarity degree component along vertical
direction: $Cv5[i,j] = (|Z[i-1,j-1] - G[i-1,j]| + |Z[i-1,j+1] - G[i-1,j]| + |Z[i+1,j-1] - G[i+1,j]| + |Z[i+1,j+1] - G[i+1,j]|) / 4$

5 $\cdots \text{formula 18}$

B-G (R-G) similarity degree component along
horizontal direction: $Ch5[i,j] = (|Z[i-1,j-1] - G[i,j-1]| + |Z[i-1,j+1] - G[i,j+1]| + |Z[i+1,j-1] - G[i,j-1]| + |Z[i+1,j+1] - G[i,j+1]|) / 4 \cdots \text{formula 19}$

10 luminance similarity degree component along vertical
direction: $Cv6[i,j] = (|Y[i,j-1] - Y[i,j]| + |Y[i,j+1] - Y[i,j]|) / 2 \cdots \text{formula 20}$

luminance similarity degree component along
horizontal direction: $Ch6[i,j] = (|Y[i-1,j] - Y[i,j]| + |Y[i+1,j] - Y[i,j]|) / 2 \cdots \text{formula 21}$

In formulae 20 and 21, $Y[i,j]$ represents a value
calculated through

$Y[i,j] = (4 \cdot A[i,j] + 2 \cdot (A[i,j-1] + A[i,j+1] + A[i-1,j] + A[i+1,j]) + A[i-1,j-1] + A[i-1,j+1] + A[i+1,j-1] + A[i+1,j+1]) / 16 \cdots \text{formula 22}$

, which is equivalent to the luminance value generated
through filtering processing in which the color
information corresponding to the color components at
nearby pixels around the interpolation target pixel is
25 averaged at a ratio of R:G:B = 1:2:1. It is to be noted

that A[i,j] represents an arbitrary set of color information on the Bayer array which may assume a G value or a Z value depending upon the position at which the color information is provided.

5 Next, the interpolation processing unit 17 performs weighted addition of the plurality of types of similarity degree components along each direction by using weighting coefficients a1, a2, a3, a4, a5 and a6, as expressed in the follow formulae 23 and 24, to calculate a similarity
10 degree Cv0[i,j] along the vertical direction and a similarity degree Ch0[i,j] along the horizontal direction for the interpolation target pixel.

$$\text{Cv0}[i,j] = (\text{a1} \cdot \text{Cv1}[i,j] + \text{a2} \cdot \text{Cv2}[i,j] + \text{a3} \cdot \text{Cv3}[i,j] + \text{a4} \cdot \text{Cv4}[i,j] + \text{a5} \cdot \text{Cv5}[i,j] + \text{a6} \cdot \text{Cv6}[i,j]) / (\text{a1} + \text{a2} + \text{a3} + \text{a4} + \text{a5} + \text{a6})$$

15 ... formula 23

$$\text{Ch0}[i,j] = (\text{a1} \cdot \text{Ch1}[i,j] + \text{a2} \cdot \text{Ch2}[i,j] + \text{a3} \cdot \text{Ch3}[i,j] + \text{a4} \cdot \text{Ch4}[i,j] + \text{a5} \cdot \text{Ch5}[i,j] + \text{a6} \cdot \text{Ch6}[i,j]) / (\text{a1} + \text{a2} + \text{a3} + \text{a4} + \text{a5} + \text{a6})$$

... formula 24

It is to be noted that the ratio among the weighting
20 coefficients a1, a2, a3, a4, a5 and a6 in formulae 23 and 24 may be, for instance, " a1: a2: a3: a4: a5: a6: = 2:1:1:4:4:12 ."

In the first embodiment, a further improvement is achieved in the accuracy with which the similarity degrees
25 are calculated by calculating the similarity degree

components along the vertical and horizontal directions and performing weighted addition of the similarity degree components for nearby pixels around the interpolation target pixel as well as for the interpolation target pixel.

5 Namely, the interpolation processing unit 17 performs weighted addition of the results obtained by implementing weighted addition of the similarity degree components at the interpolation target pixel and the nearby pixels (Cv0[i,j], Cv0[i-1,j-1], Cv0[i-1,j+1], Cv0[i+1,j-1],
10 Cv0[i+1,j+1] and the like), through either (method 1) or (method 2) detailed below, to obtain a similarity degree Cv[i,j] along the vertical direction and a similarity degree Ch[i,j] along the horizontal direction manifesting by the interpolation target pixel.

15 (method 1)

$$Cv[i,j] = (4 \cdot Cv0[i,j] + Cv0[i-1,j-1] + Cv0[i-1,j+1] + Cv0[i+1,j-1] + Cv0[i+1,j+1]) / 8 \quad \dots \text{formula 25}$$

$$Ch[i,j] = (4 \cdot Ch0[i,j] + Ch0[i-1,j-1] + Ch0[i-1,j+1] + Ch0[i+1,j-1] + Ch0[i+1,j+1]) / 8 \quad \dots \text{formula 26}$$

20 (method 2)

$$Cv[i,j] = (4 \cdot Cv0[i,j] + 2 \cdot (Cv0[i-1,j-1] + Cv0[i+1,j-1] + Cv0[i-1,j+1] + Cv0[i+1,j+1]) + Cv0[i,j-2] + Cv0[i,j+2] + Cv0[i-2,j] + Cv0[i+2,j]) / 16 \quad \dots \text{formula 27}$$

25 Ch[i,j] = (4 · Ch0[i,j]

$$+2 \cdot (\text{Ch0}[i-1, j-1] + \text{Ch0}[i+1, j-1] + \text{Ch0}[i-1, j+1] + \text{Ch0}[i+1, j+1]) \\ + \text{Ch0}[i, j-2] + \text{Ch0}[i, j+2] + \text{Ch0}[i-2, j] + \text{Ch0}[i+2, j]) / 16$$

... formula 28

It is to be noted that while (method 1) corresponds
 5 to that weighted addition of the similarity degree
 components at the interpolation target pixel and the
 nearby pixels is implemented as illustrated in FIG. 6A,
 (method 2) corresponds to that weighted addition of the
 similarity degree components at the interpolation target
 10 pixel and the nearby pixels is implemented as illustrated
 in FIG. 6B.

The similarity degree components each calculated by
 using color information corresponding to the same color
 component such as the G-G similarity degree components, B-
 15 B (R-R) similarity degree component and the R-R (B-B)
 similarity degree components (hereafter referred to as
 "same-color similarity degree components") have been
 confirmed through testing to be suitable for use in the
 evaluation of similarity manifesting in an image with a
 20 low spatial frequency and a large colored area. The
 similarity degree components each calculated by using
 color information corresponding to different color
 components such as the G-R (G-B) similarity degree
 components and B-G (R-G) similarity degree components
 25 (hereafter referred to as "different-color similarity

degree components") have been confirmed through testing to be suitable for use in the evaluation of similarity manifesting in an image with a high spatial frequency and a large achromatic image area. In addition, the luminance
5 similarity degree components have been confirmed through testing to be suitable for use in the evaluation of similarity manifesting in an image containing both a colored area and an image area with a fairly high spatial frequency.

10 In other words, the evaluation of similarity manifesting in various types of images can be achieved with a high degree of accuracy by using similarity degrees obtained through weighted addition of same-color similarity degree components, different-color similarity
15 degree components and luminance similarity degree components.

In addition, the functions of the three types of similarity degree components calculated as the same-color similarity degree components (the G-G similarity degree
20 components, the B-B (R-R) similarity degree components and the R-R (B-B) similarity degree components) in the similarity evaluation can be complemented by one another and the functions of the two types of similarity degrees components calculated as the different-color similarity
25 degree components (the G-R (G-B) similarity degree

components and the B-G (R-G) similarity degree components) in the similarity evaluation, too, can be complemented by each other .

Furthermore, in the first embodiment, the vertical
5 similarity degree $C_v[i,j]$ and the horizontal similarity degree $C_h[i,j]$ are calculated through weighted addition of the results of weighted addition of similarity degree components at the interpolation target pixel and the results of weighted addition of similarity degree
10 components at nearby pixels. Thus, the continuity between the color information at the interpolation target pixel and the color information at the pixels located near the interpolation target pixel is readily reflected in the vertical similarity degree $C_v[i,j]$ and the horizontal
15 similarity degree $C_h[i,j]$.

In particular , the vertical similarity degree $C_v[i,j]$ and the horizontal similarity degree $C_h[i,j]$ calculated through (method 2) reflect color information corresponding to the color components at pixels over a
20 wide range and thus, are effective in the similarity evaluation of an image manifesting a pronounced magnification chromatic aberration.

It is to be noted that the vertical similarity degree $C_v[i,j]$ and the horizontal similarity degree $C_h[i,j]$ in
25 the first embodiment indicate more marked similarity as

their values become smaller.

After the vertical similarity degree $Cv[i,j]$ and the horizontal similarity degree $Ch[i,j]$ are calculated as described above, the interpolation processing unit 17
5 compares the similarity along the vertical direction and the similarity along the horizontal direction manifesting at the interpolation target pixel (hereafter referred to as the "vertical/horizontal similarity") based upon the vertical similarity degree $Cv[i,j]$ and the horizontal
10 similarity degree $Ch[i,j]$ (FIG. 4 S2). Then, it sets one of the following values for an index $HV[i,j]$ which indicates the vertical/horizontal similarity based upon the results of the comparison.

For instance, if $|Cv[i,j] - Ch[i,j]| > T1$ and $Cv[i,j]$
15 $< Ch[i,j]$ are true with regard to a given threshold value $T1$, the interpolation processing unit 17 judges that a more marked similarity is manifested along the vertical direction than along the horizontal direction and sets 1 for the index $HV[i,j]$ (FIG. 4 S3), if; $|Cv[i,j] - Ch[i,j]|$
20 $> T1$ and $Cv[i,j] > Ch[i,j]$ are true, the interpolation processing unit 17 judges that a more marked similarity is manifested along the horizontal direction than along the vertical direction and sets -1 for the index $HV[i,j]$ (FIG. 4 S4) and if; $|Cv[i,j] - Ch[i,j]| \leq T1$ is true, the
25 interpolation processing unit 17 judges that the degree of

similarity manifested along the horizontal direction and along the vertical direction are essentially the same and sets 0 for the index $HV[i,j]$ (FIG. 4 S5).

It is to be noted that the threshold value $T1$ is used to prevent an erroneous judgment that the similarity along either direction is more marked from being made due to noise when the difference between the vertical similarity degree $Cv[i,j]$ and the horizontal similarity degree $Ch[i,j]$ is very little. Accordingly, by setting a high value for the threshold value $T1$ when processing a color image with a great deal of noise, an improvement in the accuracy of the vertical/horizontal similarity judgment is achieved.

Next, the interpolation processing unit 17 calculates a similarity degree $C45[i,j]$ along the diagonal 45° direction and a similarity degree $C135[i,j]$ along the diagonal 135° degree direction for the interpolation target pixel (FIG. 4 S6).

Now, details of the processing implemented in the first embodiment to calculate the diagonal 45° similarity degree $C45[i,j]$ and the diagonal 135° similarity degree $C135[i,j]$ are explained.

First, the interpolation processing unit 17 calculates a plurality of types of similarity degree components along the diagonal 45° direction and the

45° direction:

$$C45_4[i,j] = (|Z[i+1,j-1] - Z[i,j]| + |Z[i-1,j+1] - Z[i,j]|) / 2$$

... formula 35

B-R (R-B) similarity degree component along the diagonal

5 135° direction:

$$C135_4[i,j] = (|Z[i-1,j-1] - Z[i,j]| + |Z[i+1,j+1] - Z[i,j]|) / 2$$

... formula 36;

Next, the interpolation processing unit 17 calculates a similarity degree $C45_0[i,j]$ along the diagonal 45°

10 direction and a similarity degree $C135_0[i,j]$ along the diagonal 135° direction through weighted addition of the plurality of types of similarity degree components performed along each of the two directions by using weighting coefficients $b1$, $b2$, $b3$ and $b4$, as expressed in

15 the following formulae 37 and 38.

$$C45_0[i,j] = (b1 \cdot C45_1[i,j] + b2 \cdot C45_2[i,j] + b3 \cdot C45_3[i,j] + b4 \cdot C45_4[i,j]) / (b1 + b2 + b3 + b4) \quad \text{... formula 37}$$

$$C135_0[i,j] = (b1 \cdot C135_1[i,j] + b2 \cdot C135_2[i,j] + b3 \cdot C135_3[i,j] + b4 \cdot C135_4[i,j]) / (b1 + b2 + b3 + b4) \quad \text{... formula 38}$$

20 It is to be noted that the ratio of the weighting coefficients $b1$, $b2$, $b3$ and $b4$ in formulae 37 and 38 may be, for instance, " $b1:b2:b3:b4 = 2:1:1:2$."

In the first embodiment, a further improvement is achieved in the accuracy with which the similarity degrees

25 are calculated by calculating the similarity degree

components along the diagonal 45° direction and the
diagonal 135° direction and performing weighted addition
of the similarity degree components for nearby pixels
around the interpolation target pixel as well as for the
5 interpolation target pixel.

Namely, the interpolation processing unit 17 performs
weighted addition of the results obtained by implementing
weighted addition of the similarity degree components at
the interpolation target pixel and the nearby pixels
10 (C45_0[i,j], C45_0[i-1,j-1], C45_0[i-1,j+1], C45_0[i+1,j-
1], C45_0[i+1,j+1] and the like) through either (method 1)
or (method 2) detailed below, to obtain a similarity
degree C45[i,j] along the diagonal 45° direction and a
similarity degree C135[i,j] along the diagonal 135°
15 direction manifesting by the interpolation target pixel
(equivalent to implementing weighted addition of
similarity degree components at the interpolation target
pixel and the nearby pixels as illustrated in FIGS. 6A and
6B).

20 (method 1)

$$C45[i,j] = (4 \cdot C45_0[i,j] + C45_0[i-1,j-1] + C45_0[i+1,j-1] \\ + C45_0[i-1,j+1] + C45_0[i+1,j+1]) / 8 \quad \text{... formula 39}$$

$$C135[i,j] = (4 \cdot C135_0[i,j] + C135_0[i-1,j-1] + C135_0[i+1,j-1] \\ + C135_0[i-1,j+1] + C135_0[i+1,j+1]) / 8 \quad \text{... formula 40}$$

25 (method 2)

$$C45[i,j] = (4 \cdot C45_0[i,j] + 2 \cdot (C45_0[i-1,j-1] + C45_0[i+1,j-1] + C45_0[i-1,j+1] + C45_0[i+1,j+1]) + C45_0[i,j-2] + C45_0[i,j+2] + C45_0[i-2,j] + C45_0[i+2,j]) / 16$$
 ... formula 41

5
$$C135[i,j] = (4 \cdot C135_0[i,j] + 2 \cdot (C135_0[i-1,j-1] + C135_0[i+1,j-1] + C135_0[i-1,j+1] + C135_0[i+1,j+1]) + C135_0[i,j-2] + C135_0[i,j+2] + C135_0[i-2,j] + C135_0[i+2,j]) / 16$$
 ... formula 42

It is to be noted that the weighted addition of the plurality of similarity degree components and the consideration of the evaluation of similarity degrees at the nearby pixels with regard to the diagonal 45° similarity degree C45[i,j] and the diagonal 135° similarity degree C135[i,j] thus calculated achieves the same function as that with regard to the vertical similarity degree Cv[i,j] and the horizontal similarity degree Ch[i,j]. In addition, the diagonal 45° similarity degree C45[i,j] and the diagonal 135° similarity degree C135[i,j] in the first embodiment indicate more marked similarity as their values become smaller.

After the diagonal 45° similarity degree C45[i,j] and the diagonal 135° similarity degree C135[i,j] are calculated, the interpolation processing unit 17 compares the similarity along the diagonal 45° direction and the similarity along the diagonal 135° direction manifesting

at the interpolation target pixel (hereafter referred to as the "diagonal similarity") based upon the diagonal 45° similarity degree C45[i,j] and the diagonal 135° similarity degree C135[i,j] (FIG. 4 S7). Then, it sets
5 one of the following values for an index DN[i,j] which indicates the diagonal similarity based upon the results of the comparison.

For instance, if; $|C45[i,j] - C135[i,j]| > T2$ and $C45[i,j] < C135[i,j]$ are true with regard to a given
10 threshold value T2, the interpolation processing unit 17 judges that a more marked similarity is manifested along the diagonal 45° direction than along the diagonal 135° direction and sets 1 for the index DN[i,j] (FIG. 4 S8),
if; $|C45[i,j] - C135[i,j]| > T2$ and $C45[i,j] > C135[i,j]$
15 are true, the interpolation processing unit 17 judges that a more marked similarity is manifested along the diagonal 135° direction than along the diagonal 45° direction and sets -1 for the index DN[i,j] (FIG. 4 S9) and if;
 $|C45[i,j] - C135[i,j]| \leq T2$ is true, the interpolation
20 processing unit 17 judges that the degree of similarity manifesting along the diagonal 45° direction and along the diagonal 135° direction are essentially the same and sets 0 for the index DN[i,j] (FIG. 4 S10).

It is to be noted that the threshold value T2 is used
25 to prevent an erroneous judgment that the similarity along

either direction is more marked from being made due to noise.

Next, the interpolation processing unit 17 ascertains the specific values of the index HV[i,j] indicating the vertical/horizontal similarity and the index DN[i,j] indicating the diagonal similarity (FIG. 4 S11) and classifies the class of the similarity manifesting at the interpolation target pixel as one of the following; case 1 ~ case 9.

- 10 case 1: (HV[i,j], DN[i,j]) = (1, 1): marked
similarity manifesting along the vertical direction and
the diagonal 45° direction
- case 2: (HV[i,j], DN[i,j]) = (1, 0): marked
similarity manifesting along the vertical direction
- 15 case 3: (HV[i,j], DN[i,j]) = (1, -1): marked
similarity manifesting along the vertical direction and
the diagonal 135° direction
- case 4: (HV[i,j], DN[i,j]) = (0, 1): marked
similarity manifesting along the diagonal 45° direction
- 20 case 5: (HV[i,j], DN[i,j]) = (0, 0): marked
similarity manifesting along all the directions or little
similarity manifesting along all the directions
- case 6: (HV[i,j], DN[i,j]) = (0, -1): marked
similarity manifesting along the diagonal 135° direction
- 25 case 7: (HV[i,j], DN[i,j]) = (-1, 1): marked

similarity manifesting along the horizontal direction and the diagonal 45° direction

case 8: $(HV[i,j], DN[i,j]) = (-1, 0)$: marked

similarity manifesting along the horizontal direction

5 case 9: $(HV[i,j], DN[i,j]) = (-1, -1)$: marked

similarity manifesting along the horizontal direction and the diagonal 135° direction.

FIG. 7 illustrates the directions along which marked similarity manifests, as indicated by the values of

10 $HV[i,j], DN[i,j]$

In FIG. 7, there is no directional indication that corresponds to "case 5: $(HV[i,j], DN[i,j]) = (0, 0)$." A marked similarity manifesting along all the directions or only a slight similarity manifesting along all the
15 directions as in case 5 means that the interpolation target pixel is contained within a flat area or is an isolated point (an image area manifesting a lower degree of similarity to nearby pixels and having a high spatial frequency).

20 Next, the interpolation processing unit 17 calculates the green color interpolation value $G[i,j]$ as indicated below based upon the results of the judgment explained above.

In case 1, $G[i,j] = Gv45[i,j]$: FIG. 4 S12

25 In case 2, $G[i,j] = Gv[i,j]$: FIG. 4 S13

In case 3, $G[i,j] = Gv135[i,j]$: FIG. 4 S14

In case 4, $G[i,j] = (Gv45[i,j] + Gh45[i,j]) / 2$: FIG.

4 S15

In case 5, $G[i,j] = (G_v[i,j] + G_h[i,j]) / 2$: FIG. 4

5 S16

In case 6, $G[i,j] = (Gv135[i,j] + Gh135[i,j]) / 2 :$

FIG. 4 S17

In case 7, $G[i,j] = Gh45[i,j]$: FIG. 4 S18

In case 8, $G[i,j] = Gh[i,j]$: FIG. 4 S19

```
10      In case 9, G[i,j] = Gh135[i,j] : FIG. 4 S20, with
```

$$Gv[i, j] = (G[i, j - 1] + G[i, j + 1]) / 2$$

$$+ (2 \cdot Z[i, j] - Z[i, j - 2] - Z[i, j + 2]) / 8$$

$$+ (2 \cdot G[i-1, j] - G[i-1, j-2] - G[i-1, j+2])$$

$$+2 \cdot G[i+1, j] - G[i+1, j-2] - G[i+1, j+2]) / 16 \quad \dots \quad \text{formula 43}$$

```
15    Gv45[i,j] = (G[i,j-1]+G[i,j+1])/2
```

$$+ (2 \cdot Z[i, j] - Z[i, j-2] - Z[i, j+2]) / 8$$

$$+ (2 \cdot Z[i-1, j+1] - Z[i-1, j-1] - Z[i-1, j+3])$$

$$+2 \cdot Z[i+1, j-1] - Z[i+1, j-3] - Z[i+1, j+1]) / 16 \quad \dots \quad \text{formula 44}$$

$$G_{v135}[i, j] = (G[i, j-1] + G[i, j+1]) / 2$$

```
20      + (2 * Z[i, j] - Z[i, j - 2] - Z[i, j + 2]) / 8
```

$$+ (2 \cdot Z[i-1, j-1] - Z[i-1, j-3] - Z[i-1, j+1])$$

$$+2 \cdot Z[i+1, j+1] - Z[i+1, j-1] - Z[i+1, j+3]) / 16 \quad \dots \text{ formula 45}$$

$$Gh[i, j] = (G[i-1, j] + G[i+1, j]) / 2$$

$$+ (2 \cdot Z[i, j] - Z[i-2, j] - Z[i+2, j]) / 8$$

```
25      + (2*G[i,j-1]-G[i-2,j-1]-G[i+2,j-1]
```


$$+2 \cdot G[i, j+1] - G[i-2, j+1] - G[i+2, j+1]) / 16 \quad \dots \text{ formula 46}$$
$$Gh45[i,j] = (G[i-1,j] + G[i+1,j]) / 2$$
$$+ (2 \cdot Z[i, j] - Z[i-2, j] - Z[i+2, j]) / 8$$
$$+ (2 \cdot Z[i+1, j-1] - Z[i-1, j-1] - Z[i+3, j-1])$$

5 $+2 \cdot Z[i-1, j+1] - Z[i-3, j+1] - Z[i+1, j+1]) / 16$... formula 47

$$Gh135[i,j] = (G[i-1,j] + G[i+1,j]) / 2$$
$$+ (2 \cdot Z[i, j] - Z[i-2, j] - Z[i+2, j]) / 8$$
$$+ (2 \cdot Z[i-1, j-1] - Z[i-3, j-1] - Z[i+1, j-1])$$
$$+2 \cdot Z[i+1, j+1] - Z[i-1, j+1] - Z[i+3, j+1]) / 16 \dots \text{ formula 48}$$

FIG. 8 shows the positions of the color information used to calculate the green color interpolation value $G[i,j]$. In FIG. 8, the color information at the circled pixels is used as a contributing factor in the curvature information that constitutes the green color interpolation value $G[i,j]$.

In each of formulae 43 ~ 48, the first term constitutes the "local average information of the green color component" and corresponds to the primary terms in formulae 1 and 2. The second term represents the "local curvature information based upon a color component matching a color component at the interpolation target pixel" and the third term represents the "local curvature information based upon a color component other than the color component at the interpolation target pixel." It is to be noted that the curvature information in the second

and third terms is obtained through quadratic differentiation of the color components. To explain this point by referring to formula 44, in the second term of formula 44, the difference between the color information $Z[i,j]$ and the color information $Z[i,j-2]$ and the difference between the color information $Z[i,j+2]$ and the color information $Z[i,j]$ are obtained and then the difference between these differences is ascertained. In the third term the difference between the color information $Z[i-1,j+1]$ and the color information $Z[i-1,j-1]$ and the difference between the color information $Z[i-1,j+3]$ and the color information $Z[i-1,j+1]$ are obtained with the difference between these differences then ascertained and the difference between the color information $Z[i+1,j-1]$ and the color information $Z[i+1,j+3]$ and the difference between the color information $Z[i+1,j+1]$ and the color information $Z[i+1,j-1]$ are obtained with the difference between these differences then ascertained.

In Gv45[i,j], the "local curvature information based upon a color component matching the color component at the interpolation target pixel" is local curvature information with directionality manifesting along the vertical direction, and the "local curvature information based upon a color component other than the color component at the

interpolation target pixel" is local curvature information with directionality manifesting along the vertical direction and the diagonal 45° direction. In Gv135[i,j], the "local curvature information based upon a color component matching the color component at the interpolation target pixel" is local curvature information with directionality manifesting along the vertical direction, and the "local curvature information based upon a color component other than the color component at the interpolation target pixel" is local curvature information with directionality manifesting along the vertical direction and the diagonal 135° direction. In Gh45[i,j], the "local curvature information based upon a color component matching the color component at the interpolation target pixel" is local curvature information with the directionality manifesting along the horizontal direction, and the "local curvature information based upon a color component other than the color component at the interpolation target pixel" is local curvature information with directionality manifesting along the horizontal direction and the diagonal 45° direction. In Gh135[i,j], the "local curvature information based upon a color component matching the color component at the interpolation target pixel" is local curvature information with directionality manifesting along the horizontal

direction, and the "local curvature information based upon
a color component other than the color component at the
interpolation target pixel" is local curvature information
with directionality manifesting along the horizontal
5 direction and the diagonal 135° direction.

In addition, the "local curvature information based
upon a color component matching the color component at the
interpolation target pixel" and the "local curvature
information based upon a color component other than the
10 color component at the interpolation target pixel" in
 $G_v[i,j]$ are both local curvature information with
directionality manifesting along the vertical direction,
and the "local curvature information based upon a color
component matching the color component at the
15 interpolation target pixel" and the "local curvature
information based upon a color component other than the
color component at the interpolation target pixel" in
 $G_h[i,j]$ are both local curvature information with
directionality manifesting along the horizontal direction.

20 In other words, in the first embodiment, the local
average information of the green color component is
corrected by using the "local curvature information based
upon a color component matching the color component at the
interpolation target pixel" and the "local curvature
25 information based upon a color component other than the

color component at the interpolation target pixel."

For instance, when marked similarity manifests along the diagonal directions and the green color interpolation value is calculated by using Gv45[i,j], Gv135[i,j],

5 Gh45[i,j] and Gh135[i,j] (case 1, case 3, case 4, case 6, case 7 or case 9), the local average information of the green color component (the primary term) is corrected by using the local curvature information based upon the red color component and the local curvature information based
10 upon the blue color component at phases that are opposite from each other. In such a case, color information in the individual color components to be used to calculate the local curvature information corresponding to each color component is obtained from pixels that are present on both
15 sides of a line drawn along a direction judged to manifest marked similarity.

Thus, even when the color information corresponding to the red color component and the color information corresponding to the blue color component are offset
20 relative to the color information corresponding to the green color component due to magnification chromatic aberration, as illustrated in FIG. 9A (equivalent to a drawing achieved by superimposing FIG. 18B on FIG. 18C), the primary term is corrected in correspondence to the
25 average quantity of change in the color information

09877002 "0001.01

corresponding to the red color component and the color
information corresponding to the blue color component. As
a result, by adopting the first embodiment, the primary
term can be corrected for a desired pixel even if there is
5 magnification chromatic aberration at the photographic
optical system 12, with the overshoot and the undershoot
occurring as a result of the G interpolation processing
disclosed in USP No. 5,629,734 canceled out by each other.
Consequently, the occurrence of color artifacts
10 attributable to over correction can be reduced in the
first embodiment.

It is to be noted that while an overshoot may also
occur when correcting a primary term constituted of color
information corresponding to the blue color component as
15 well as when correcting a primary term constituted of
color information corresponding to the red color component,
overshoot values corresponding to the individual color
components are averaged in the first embodiment and thus,
the average value does not exceed an overshoot value
20 resulting from the G interpolation processing disclosed in
USP No. 5,629,734. In addition, even if an undershoot
occurs when correcting a primary term constituted of color
information corresponding to the blue color component or
correcting a primary term constituted of color information
25 corresponding to the red color component, the undershoot

value in the first embodiment never exceeds the undershoot value resulting from the G interpolation processing disclosed in USP No. 5,629,734.

09876543210
In the first embodiment, the image data to undergo
5 the G interpolation processing are arranged in a Bayer array as shown in FIGS. 2A and 2B, with the color information corresponding to the red color component and the color information corresponding to the blue color component positioned diagonally to each other. Thus, if
10 color information corresponding to the blue color component is provided at the interpolation target pixel, for instance, the local curvature information based upon the red color component to be used to correct the primary term is calculated by using color information
15 corresponding to the red color component at pixels positioned along a diagonal direction along which marked similarity to the interpolation target pixel manifests. In addition, the green color interpolation value is calculated by using the color information at pixels set
20 along a diagonal direction distanced from the interpolation target pixel such as $Z[i-1, j+3]$ and $Z[i+1, j-3]$ in formula 44, $Z[i-1, j-3]$ and $Z[i+1, j+3]$ in formula 45, $Z[i+3, j-1]$ and $Z[i-3, j+1]$ in formula 47 and $Z[i-3, j-1]$ and $Z[i+3, j+1]$ in formula 48.

25 As a result, in the G interpolation processing in the

first embodiment which requires a highly accurate judgment
on the diagonal similarity, the interpolation processing
unit 17 achieves a high degree of accuracy in the
judgement of the diagonal similarity by using a plurality
5 of sets of color information when calculating a plurality
of types of similarity degree components along the
diagonal 45° direction and the diagonal 135° direction.

In other words, the accuracy of the interpolation
processing is improved through a highly accurate judgment
10 on the diagonal similarity in the first embodiment.

In addition, if marked similarity manifests along the
vertical direction or the horizontal direction and thus
the green interpolation value is calculated using $G_v[i,j]$
or $G_h[i,j]$ (case 2 or case 8), local curvature information
15 based upon the green color component is used as the "local
curvature information based upon a color component other
than the color component at the interpolation target
pixel" and the local average information of the green
color component is corrected by using local curvature
20 information based upon the red color component or the blue
color component and local curvature information based upon
the green color component.

Under normal circumstances, due to the effect of
magnification chromatic aberration, the red color
25 component, the green color component and the blue color

component may have relative positional offsets in order of wavelength, i.e. in order of red color, green color and blue color. And the green color component positions between the red color component and the blue color

5 component. Thus, if color information corresponding to the red color component is provided at the interpolation target pixel, the local curvature information based upon the green color component can be used as a component at a phase opposite from the phase of the local curvature

10 information based upon the red color component to reduce the occurrence of color artifacts resulting from over correction. Also, in the same manner, if color

information corresponding to the blue color component is provided at the interpolation target pixel, the local

15 curvature information based upon the green color component can be used as a component at a phase opposite from the phase of the local curvature information based upon the blue color component to reduce the occurrence of color artifacts resulting from over correction.

20 In the following explanation of the RB interpolation processing operation, the RB interpolation processing implemented in the prior art is first described and then the R interpolation processing in FIG. 5 in the RB interpolation processing implemented in the first
25 embodiment is explained (an explanation of the B

interpolation processing is omitted).

A known example of the RB interpolation processing in the prior art is linear interpolation processing implemented in a color difference space in which after
5 calculating color differences at all the pixels (values each obtained by subtracting the value indicated by color information corresponding to the green color component from the value indicated by color information
10 corresponding to the red color component (or the blue color component)), one of the three different types of processing (1) - (3) described below is implemented on each interpolation target pixel to calculate the interpolation value.

(1) If a color component missing at the interpolation
15 target pixel is present at the two pixels adjacent to the interpolation target pixel along the vertical direction, the interpolation target value is calculated as a value achieved by adding the color information corresponding to the green color component at the interpolation target
20 pixel to the average of the color differences at the two pixels.

(2) If a color component missing at the interpolation
target pixel is present at the two pixels adjacent to the interpolation target pixel along the horizontal direction,
25 the interpolation target value is calculated as a value

achieved by adding the value indicated by the color information corresponding to the green color component at the interpolation target pixel to the average of the color differences at the two pixels.

- 5 (3) If a color component missing at the interpolation target pixel is present at the four pixels adjacent to the interpolation target pixel along the diagonal directions, the interpolation target value is calculated as a value achieved by adding the value indicated by the color
- 10 information corresponding to the green color component at the interpolation target pixel to the average of the color differences at the four pixels.

In addition, interpolation processing that incorporates nonlinear median processing, which is more

15 effective in preventing color artifacts compared to linear processing in a color difference space is also implemented in the prior art.

In the art disclosed in USP No. 5,799,113, in which video signals provided in one of the following

20 colorimetric systems, RGB, YUV and YCbCr, undergo culled compression at a resolution of 1/4 to reduce the transmission volume, nonlinear median processing is implemented to restore the video signals to the original resolution by interpolating 3-component data at the culled

25 pixels which have been lost. For instance, if the video

signals are provided in the YCbCr colorimetric system, the interpolation values for the luminance component Y and the interpolation values corresponding to the color components Cb and Cr at the culled pixels marked O, Δ and X in FIGS.

5 10A ~ 10C are calculated through identical arithmetic processing. It is to be noted that in order to retain the structure at an edge, the pixel marked X alone is interpolated by using the median value (median) of the values at four nearby pixels, the pixels marked O are each
10 interpolated by using the average of the values at the pixels adjacent along the horizontal direction and the pixels marked Δ are each interpolated by using the average of the values at the pixels adjacent along the vertical direction.

15 However, while the interpolation processing implemented as described above is effective in restoring the image quality in a dynamic image, it is not suited for processing a still image that requires high definition. Namely, the art disclosed in USP No. 5,799,113, in which
20 the luminance component Y and the color components Cr and Cb are handled in exactly the same way, achieves only a very low degree of accuracy with regard to the interpolation values for the luminance component Y which determines the resolution. In addition, since the
25 luminance component Y is interpolated by using the median,

the likelihood of the image structure becoming lost is high. Furthermore, there is a concern that color artifacts may spread when the data are converted to the RGB colorimetric system.

5 In an electronic camera which employs an image-capturing sensor constituted by arranging R, G and B color filters in a Bayer array to generate a still image, the interpolation processing on the green color component which is equivalent to the luminance component with a high spatial frequency (G interpolation processing) can be implemented with a very high degree of accuracy by using similarity manifesting between the interpolation target pixel and nearby pixels and calculating the interpolation value using a plurality of color components, as explained
10 earlier. In such an electronic camera, after implementing high-definition interpolation processing on the green color component, which most faithfully reflects the high-frequency information in the image data, the interpolation processing on the red color component and the blue color
15 component is achieved through linear interpolation in color difference spaces relative to the green color component to reduce color artifacts by reflecting the high-frequency information in the image data in the red color component and the blue color component.

25 For instance, if the sets of color information at

individual pixels are arranged one-dimensionally in the order of (R1, G2, R3), the red color interpolation value is calculated through;

$R2 = (R1 + R3) / 2 + (2 \cdot G2 - G1 - G3) / 2$... formula 49. In the formula,

5 G2 represents color information corresponding to the green color component in the original image and G1 and G3 each represent a green color interpolation value obtained through the G interpolation processing.

However, this RB interpolation processing poses a
10 problem in that the color artifact is allowed to remain in the vicinity of an isolated point (an image area manifesting only slight similarity to nearby pixels and having a high spatial frequency). In the prior art, this type of color artifact is often eliminated in post
15 processing, in which a and b hue planes obtained by converting the image data to the Lab colorimetric system individually undergo median filtering after the G interpolation processing and the RB interpolation processing are implemented.

20 Since a 3 x 3 (= 9 points) filter size achieves hardly any effect, the filter size must be set over a large range of 5 x 5 (= 25 points) when applying such a median filter.

In other words, in the electronic camera described
25 above, extremely heavy processing must be implemented

since both the RB interpolation processing in the prior art and the median processing must be performed in the interpolation processing on the red color component and the blue color component in a still image and also the filter size must be set over a wide range for the median processing. Furthermore, the risk of the fine structure in a colored area (hereafter referred to as a "color structure") being lost is higher when the filter size in the median processing is increased.

Accordingly, in the first embodiment, RB interpolation processing through which red color and blue color interpolation values can be calculated quickly with a high degree of accuracy without allowing any color artifacts to remain in the vicinity of an isolated point or losing the color structure is proposed. It is to be noted that the following is an explanation of the only R interpolation processing in the RB interpolation processing, given in reference to FIG. 5.

First, the interpolation processing unit 17 calculates a color difference that contains the red color component for each pixel at which color information corresponding to the red color component is present by subtracting the green color interpolation value (the value obtained through the G interpolation processing explained earlier) from the value indicated by the color

information corresponding to the red color component (FIG. 5 S1).

For instance, the interpolation processing unit 17 calculates a color difference $Cr[i,j]$ containing the red color component at a pixel at given coordinates $[i,j]$ with color information corresponding to the red color component as; $Cr[i,j]=R[i,j]-G[i,j]$... formula 50.

It is to be noted that in the first embodiment, when the color differences containing the red color component have been calculated as described above, the color differences containing the red color component are set so as to surround pixels at which color information corresponding to the red color component is missing and color information corresponding to the blue color component is present from the four diagonal directions.

The interpolation processing unit 17 interpolates the color difference containing the red color component for each of the pixels surrounded by color differences containing the red color component from the four diagonal directions (each pixel at which color information corresponding to the red color component is missing and color information corresponding to the blue color component is present in the first embodiment) by using the median of the color differences containing the red color component at the pixels set diagonally to the target pixel

(FIG. 5 S2).

Namely, in the first embodiment, the interpolation processing unit 17 calculates the color difference $Cr[m,n]$ at the pixel at given coordinates $[m,n]$ surrounded by color differences containing the red color component from the four diagonal directions as shown in FIG. 11A through;

5 $Cr[m,n] = \text{median}\{Cr[m-1,n-1], Cr[m+1,n-1],$

$Cr[m-1,n+1], Cr[m+1,n+1]\}$... formula 51.

In the formula, $\text{median}\{\}$ represents a function through which the median of a plurality of elements is calculated and, if there are an even number of elements, it takes the average of the two middle elements.

10

In the first embodiment, when the color differences containing the red color component have been calculated through formulae 50 and 51, the color differences containing the red color component are set so as to surround pixels at which color information corresponding to the red color component and color information corresponding to the blue color component are both missing from the four directions; i.e., from above, from below and from the left and the right.

15

20

The interpolation processing unit 17 interpolates the color difference containing the red color component for each of the pixels surrounded by color differences containing the red color component from the four

25

directions; i.e., from above, from below and from the left and the right (each pixel at which color information corresponding to the red color component and color information corresponding to the blue color component are both missing in the first embodiment) by using the median of the color differences containing the red color component at the pixels set above, below and to the left and the right of the pixel (FIG. 5 S3).

Namely, in the first embodiment, the interpolation processing unit 17 calculates the color difference $Cr[m,n]$ at the pixel at given coordinates $[m,n]$ surrounded by color differences containing the red color component from the four directions; i.e., from above, from below and from the left and the right as shown in FIG. 11B through;

$Cr[m,n] = \text{median}\{Cr[m,n-1], Cr[m-1,n],$

$Cr[m+1,n], Cr[m,n+1]\} \dots$ formula 52

Next, the interpolation processing unit 17 converts the color difference containing the red color component calculated through formula 51 or formula 52 for each pixel at which color information corresponding to the red color component is missing to a red color interpolation value by using color information corresponding to the green color component (or the green color interpolation value) (FIG. 5 S4).

Namely, the interpolation processing unit 17

calculates the red color interpolation value $R[m,n]$ for the pixel at given coordinates $[m,n]$ through;
 $R[m,n] = Cr[m,n] + G[m,n] \dots$ formula 53.

The median processing described above is implemented
5 on the color differences representing the hue alone and is not implemented on the luminance component. In addition, when the pixel marked O in FIG. 12A is the interpolation target pixel in the R interpolation processing, the color differences containing the red color component at the
10 pixels marked X are calculated by using the color differences Cr over a 3 x 5 range, and thus, the color difference containing the red color component at the pixel marked O represents a value which is close to the results of median processing implemented by weighting the color
15 differences Cr within the 3 x 5 range. When the pixel marked Δ in FIG. 12B is the interpolation target pixel, on the other hand, the color differences containing the red color component at the pixels marked X are calculated by using the color differences Cr over a 5 x 3 range, and
20 thus, the color difference containing the red color component at the pixel marked Δ represents a value which is close to the results of median processing implemented by weighting the color differences Cr within the 5 x 3 range.

25 In other words, in the first embodiment, advantages

substantially similar to those achieved through median processing implemented over a wide range are achieved while keeping down the filter size. As a result, by adopting the first embodiment, the occurrence of color artifacts around an isolated point is reduced without destroying the color structure. Thus, a great improvement is achieved in the color artifact reduction effect over the art disclosed in USP No. 5,799,113.

In addition, since the color differences at only four points are each used in the median processing in FIG. 5 S2 and FIG. 5 S3 in the first embodiment, good processing efficiency is achieved and extremely fast median processing is enabled.

It is to be noted that while the RB interpolation processing is implemented after the G interpolation processing in the first embodiment, RB interpolation processing similar to that in the embodiment can be implemented without having to perform G interpolation processing on image data provided in the YCbCr colorimetric system with Y, Cb and Cr culled at a ratio of 4:2:0 since the luminance component Y is left intact in the image data.

(Second Embodiment)

The following is an explanation of the operation achieved in the second embodiment.

It is to be noted that since the RB interpolation processing in the second embodiment is implemented as in the first embodiment, its explanation is omitted.

In the following explanation of the G interpolation processing, a description of the operating details identical to those in the first embodiment is omitted. It is to be noted that the difference between the G interpolation processing in the second embodiment and the G interpolation processing in the first embodiment is in the values of $G_v[i,j]$, $G_{v45}[i,j]$, $G_{v135}[i,j]$, $G_h[i,j]$, $G_{h45}[i,j]$ and $G_{h135}[i,j]$ used when calculating the green interpolation value $G[i,j]$. For this reason, the flowchart of the operation in the interpolation processing unit 17 during the G interpolation processing is not provided for the second embodiment. In addition, while an explanation is given below on an assumption that the red color component is present at the interpolation target pixel as shown in FIG. 2A, the second embodiment may be adopted when implementing processing on an interpolation target pixel at which the blue color component is present, as shown in FIG. 2B.

The interpolation processing unit 17 ascertains the degrees of similarity manifesting at the interpolation target pixel as in the first embodiment (corresponds to FIG. 4 S1 ~ S11) and classifies the type of the similarity

at the interpolation target pixel as one of cases 1 ~ 9 explained earlier. Then, the interpolation processing unit 17 calculates the green color interpolation value $G[i,j]$ as indicated below.

5 In case 1, $G[i,j] = Gv45[i,j]$
 In case 2, $G[i,j] = Gv[i,j]$
 In case 3, $G[i,j] = Gv135[i,j]$
 In case 4, $G[i,j] = (Gv45[i,j] + Gh45[i,j]) / 2$
 In case 5, $G[i,j] = (Gv[i,j] + Gh[i,j]) / 2$
 10 In case 6, $G[i,j] = (Gv135[i,j] + Gh135[i,j]) / 2$ S
 In case 7, $G[i,j] = Gh45[i,j]$
 In case 8, $G[i,j] = Gh[i,j]$
 In case 9, $G[i,j] = Gh135[i,j]$, with
 $Gv[i,j] = gv[i,j] + \beta_{red} \cdot \delta Rv[i,j] + \beta_{green} \cdot \delta Gv[i,j]$
 15 ... formula 54
 $Gv45[i,j] = gv[i,j] + \alpha_{red} \cdot \delta Rv45[i,j] + \alpha_{green} \cdot \delta Gv[i,j]$
 $+ \alpha_{blue} \cdot \delta Bv45[i,j]$... formula 55
 $Gv135[i,j] = gv[i,j] + \alpha_{red} \cdot \delta Rv135[i,j] + \alpha_{green} \cdot \delta Gv[i,j]$
 $+ \alpha_{blue} \cdot \delta Bv135[i,j]$... formula 56
 20 $Gh[i,j] = gh[i,j] + \beta_{red} \cdot \delta Rh[i,j] + \beta_{green} \cdot \delta Gh[i,j]$
 ... formula 57
 $Gh45[i,j] = gh[i,j] + \alpha_{red} \cdot \delta Rh45[i,j] + \alpha_{green} \cdot \delta Gh[i,j]$
 $+ \alpha_{blue} \cdot \delta Bh45[i,j]$... formula 58
 $Gh135[i,j] = gh[i,j] + \alpha_{red} \cdot \delta Rh135[i,j] + \alpha_{green} \cdot \delta Gh[i,j]$
 25 $+ \alpha_{blue} \cdot \delta Bh135[i,j]$... formula 59

α red, α green, α blue, β red and β green in formulae 54 ~ 59 each represent a constant which may be 0 or a positive value, and they satisfy α red + α green + α blue = 1 and β red + β green = 1. In the formula

5 above, $gv[i,j]$ and $gh[i,j]$ each constitute a term corresponding to the "local average information of the green color component" and are equivalent to the primary term in formula 1 or formula 2, and $\delta Rv45[i,j]$, $\delta Rv[i,j]$, $\delta Rv135[i,j]$, $\delta Rh45[i,j]$, $\delta Rh[i,j]$, $\delta Rh135[i,j]$, δ

10 $Gv45[i,j]$, $\delta Gh[i,j]$, $\delta Bv45[i,j]$, $\delta Bv135[i,j]$, $\delta Bh45[i,j]$ and $\delta Bh135[i,j]$ each represent a term corresponding to the local curvature information in the corresponding color component.

It is to be noted that the local average information

15 of the green color component and the local curvature information based upon the individual color components are calculated as indicated below, depending upon the direction along which similarity manifests.

(local average information of the green color component)

20 $gv[i,j] = (G[i,j-1] + G[i,j+1]) / 2 \cdots$ formula 60

$gh[i,j] = (G[i-1,j] + G[i+1,j]) / 2 \cdots$ formula 61

(Local curvature information based upon the red color component)

$\delta Rv45[i,j] = kr1(2 \cdot Z[i-2,j+2] - Z[i-2,j] - Z[i-2,j+4]) / 4$

25 $+ kr2(2 \cdot Z[i,j] - Z[i,j-2] - Z[i,j+2]) / 4$

(local curvature information based upon the blue color component)

$$\delta Bv45[i,j] = (2 \cdot Z[i-1,j+1] - Z[i-1,j-1] - Z[i-1,j+3] + 2 \cdot Z[i+1,j-1] - Z[i+1,j-3] - Z[i+1,j+1]) / 8 \quad \cdots \text{ formula 70}$$

$$\delta Bv135[i,j] = (2 \cdot Z[i-1,j-1] - Z[i-1,j-3] - Z[i-1,j+1] + 2 \cdot Z[i+1,j+1] - Z[i+1,j-1] - Z[i+1,j+3]) / 8 \quad \cdots \text{ formula 71}$$

$$\delta Bh45[i,j] = (2 \cdot Z[i+1,j-1] - Z[i-1,j-1] - Z[i+3,j-1] + 2 \cdot Z[i-1,j+1] - Z[i-3,j+1] - Z[i+1,j+1]) / 8 \quad \cdots \text{ formula 72}$$

$$\delta Bh135[i,j] = (2 \cdot Z[i-1,j-1] - Z[i-3,j-1] - Z[i+1,j-1] + 2 \cdot Z[i+1,j+1] - Z[i-1,j+1] - Z[i+3,j+1]) / 8 \quad \cdots \text{ formula 73}$$

It is to be noted that FIGS. 13 and 14 show the positions of the color information used when calculating local curvature information based upon the individual color components. Namely, local curvature information corresponding to a given color component is obtained through weighted addition of the components of the curvature information calculated by using color information at the pixels contained within the area enclosed by the oval in FIG. 13 or 14.

In other words, $\delta Rv45[i,j]$ is local curvature information with directionality manifesting along the vertical direction and the diagonal 45° direction, $\delta Rv[i,j]$ is local curvature information with directionality manifesting along the vertical direction, $\delta Rv135[i,j]$ is local curvature information with directionality

manifesting along the vertical direction and the diagonal
135° direction, $\delta Rh45[i,j]$ is local curvature information
with directionality manifesting along the horizontal
direction and the diagonal 45° direction, $\delta Rh[i,j]$ is
5 local curvature information with directionality
manifesting along the horizontal direction and $\delta Rh135[i,j]$
is local curvature information with directionality
manifesting along the horizontal direction and the
diagonal 135° direction.

10 In addition, $\delta Gv[i,j]$ is local curvature information
with directionality manifesting along the vertical
direction and $\delta Gh[i,j]$ is local curvature information with
directionality manifesting along the horizontal direction.

$\delta Bv45[i,j]$ is local curvature information with
15 directionality manifesting along the vertical direction
and the diagonal 45° direction, $\delta Bv135[i,j]$ is local
curvature information with directionality manifesting
along the vertical direction and the diagonal 135°
direction, $\delta Bh45[i,j]$ is local curvature information with
20 directionality manifesting along the horizontal direction
and the diagonal 45° direction and $\delta Bh135[i,j]$ is local
curvature information with directionality manifesting
along the horizontal direction and the diagonal 135°
direction.

25 It is to be noted that the first embodiment explained

earlier is equivalent to a situation in which the ratios of the coefficients in formulae 54 ~ 59 and formulae 62 ~ 67 in the second embodiment are set at;

α red : α green : α blue = 1:0:1, β red : β green
5 = 1:1 and $kr1$: $kr2$: $kr3$ = 0:1:0.

In the second embodiment, G interpolation processing with varying characteristics and achieving various advantages can be realized by setting different ratios for these coefficients. The following is an explanation of
10 typical examples of ratio setting for the coefficients and features and advantages of the individual examples.

(example 1)

α red : α green : α blue = 1:0:1, β red : β green
= 1:1 and $kr1$: $kr2$: $kr3$ = 1:6:1.

15 By setting these ratios, the method of calculating the local curvature information based upon the red color component is changed from that adopted in the first embodiment, and the local curvature information based upon the red color component extracted from a wider range than
20 in the first embodiment is made to undergo mild low pass filtering as appropriate while taking into consideration the directionality. Thus, by adopting the settings in example 1, the overall effect for reducing over correction is improved over the first embodiment.

25 (example 2)

α red : α green : α blue = 1:1:0, β red : β green
= 1:1 and $kr1$: $kr2$: $kr3$ = 0:1:0.

Through these settings, the local curvature
information based upon the blue color component which
5 prevents an over correction attributable to the local
curvature information based upon the red color component
when similarity manifests along the diagonal direction in
the first embodiment is all substituted with local
curvature information based upon the green color component.
10 Thus, by adopting the settings in example 2, the need for
making a judgment with regard to similarity manifesting
along the diagonal directions is eliminated to simplify
the algorithm and, at the same time, the extraction of
structural information at a sufficient level is achieved
15 while preventing over correction.

(example 3)

α red : α green : α blue = 0:1:0, β red : β green
= 0:1 and $kr1$: $kr2$: $kr3$ = setting not required

By adopting these settings, the local curvature
20 information based upon the green color component used to
prevent over correction of the red color component in
example 2 is now used as the main element in the
correctional term. The structural information can be
extracted even when the correctional term is constituted
25 only of the curvature information based upon the green

color component. This means that the curvature information based upon the green color component, too, contains a great deal of structural information equivalent to the curvature information based upon the red color component that passes through the center. In addition, by adopting the settings in example 3, a correction is performed with local curvature information based upon the same color component, i.e., the green color component, as the color component of the average information constituting the primary term. Thus, through the settings in example 3, no over correction occurs and the need for performing a judgment with regard to similarity manifesting along the diagonal directions is eliminated as in example 2, resulting in simplification of the algorithm.

(example 4)

α red : α green : α blue = 0:0:1, β red : β green = 0:1 and $kr1$: $kr2$: $kr3$ = setting not required

The relationship of this example to the first embodiment is similar to the relationship between example 2 and example 3, and by adopting these settings, the curvature information based upon the color component used to prevent an over correction of the local curvature information based upon the red color component is now utilized as the main element in the correctional term.

While it is not possible to prevent over correction

attributable to local curvature information based upon the
blue color component through the settings in example 4,
advantages comparable to those in the first embodiment are
achieved with regard to the extractions of the local
5 structural information.

(example 5)

α red : α green : α blue = 1:1:1, β red : β green
= 1:1 and $kr1$: $kr2$: $kr3$ = 1:0:1

These settings represent an example of ratios of the
10 coefficients effective even when the local curvature
information based upon the red color component that passes
through the center is not used as a measure against over
correction occurring at the settings in example 4. By
adopting the settings in example 5, the degree of over
15 correction attributable to local curvature information
based upon the blue color component can be reduced with
the local curvature information based upon the red color
component obtained from nearby pixels when similarity
manifests along the diagonal directions, while achieving
20 the advantage of extracting the local structural
information as in example 3 and example 4.

(Third Embodiment)

The following is an explanation of the operation
achieved in the third embodiment.

25 It is to be noted that since the RB interpolation

processing in the third embodiment is implemented as in the first embodiment, its explanation is omitted. However, in the third embodiment, color differences containing the red color component are interpolated for some of the
5 pixels at which color information corresponding to the green color component is present (equivalent to the pixels provided with G color filters) through formula 51 presented earlier, and color differences containing the red color component are interpolated for the remaining
10 pixels at which color information corresponding to the green color component is present and for the pixels at which color information corresponding to the blue color component is present through formula 52.

The following is an explanation of the G
15 interpolation processing.

Since the closest pixels at which the green color component (the closest green color component) is present are located along the horizontal direction relative to the pixel to undergo the G interpolation processing as shown
20 in FIGS. 3A and 3B in the third embodiment, it is not necessary to calculate the similarity degrees or to judge the direction along which similarity manifests as required in the first embodiment during the G interpolation processing. However, the calculation of similarity
25 degrees and judgment with regard to the direction along

which similarity manifests may be performed along the diagonal 45° direction and the diagonal 135° direction in which the second closest pixels with green color component (the second closest green color component) are present.

5 In the third embodiment, the interpolation processing unit 17 calculates the green color interpolation value $G[i,j]$ through the following formula 74 based upon the image data arranged as shown in FIGS. 3A and 3B.

$$\begin{aligned} G[i,j] = & (G[i-1,j] + G[i+1,j]) / 2 \\ & + (2 \cdot Z[i,j] - Z[i-2,j] - Z[i+2,j]) / 8 \\ & + (2 \cdot Z[i,j-1] - Z[i-2,j-1] - Z[i+2,j-1] \\ & + 2 \cdot Z[i,j+1] - Z[i-2,j+1] - Z[i+2,j+1]) / 16 \quad \text{... formula 74} \end{aligned}$$

10 In formula 74, the first term represents the "local average information of the green color component", which is equivalent to the primary terms in formula 1 and
15 formula 2. In addition, while the second term represents the "local curvature information based upon a color component matching the color component at the interpolation target pixel" and the third term represents
20 the "local curvature information based upon a color component other than the color component at the interpolation target pixel", the third term constitutes the "local curvature information based upon the blue color component" if color information corresponding to the red
25 color component is present at the interpolation target

pixel (FIG. 3A), whereas the third term constitutes the
"local curvature information based upon the red color
component" if color information corresponding to the blue
color component is present at the interpolation target
5 pixel (FIG. 3B).

In other words, the local average information of the
green color component (the primary term) is corrected by
using the local curvature information based upon the red
color component and the local curvature information based
10 upon the blue color component at phases opposite from each
other in the third embodiment.

As a result, as in the first embodiment, even when
the color information corresponding to the red color
component and the color information corresponding to the
15 blue color component are offset relative to the color
information corresponding to the green color component due
to a magnification chromatic aberration, the primary term
is corrected in correspondence to the average change in
quantity in the color information corresponding to the red
20 color component and the color information corresponding to
the blue color component in the third embodiment (see FIGS.
9A and 9B). Thus, even when there is a magnification
chromatic aberration at the photographic optical system 12,
the primary term can be corrected for a desired pixel with
25 the overshoot and undershoot occurring in the G

interpolation processing disclosed in USP No. 5,629,734
canceling out each other in the third embodiment.
Consequently, the occurrence of color artifacts due to
over correction can be reduced by adopting the third
5 embodiment.

(Fourth Embodiment)

The following is an explanation of the operation
achieved in the fourth embodiment.

It is to be noted that since the RB interpolation
10 processing in the fourth embodiment is implemented as in
the first embodiment, its explanation is omitted.

In the following explanation of the G interpolation
processing, operating details identical to those in the
first embodiment are not explained. It is to be noted
15 that the difference between the G interpolation processing
in the fourth embodiment and the G interpolation
processing in the first embodiment is in the operation
performed after a judgment is made with regard to degrees
of similarity manifested by the interpolation target pixel.
20 For this reason, a flowchart of the operation performed at
the interpolation processing unit 17 during the G
interpolation processing in the fourth embodiment is not
provided.

The interpolation processing unit 17 ascertains
25 degrees of similarity manifesting by the interpolation

target pixel as in the first embodiment (corresponds to FIG. 4 S1 ~ S11) and classifies the type of similarity at the interpolation target pixel as one of case 1 ~ 9 explained earlier.

5 Then, the interpolation processing unit 17 calculates the inclination $Gk[i,j]$ of the green color component and the inclination $Zk[i,j]$ of the red color component (or the blue color component) relative to the direction perpendicular to the direction judged to manifest marked
10 similarity as indicated below.

 In case1,

$$Gk[i,j] = ((G[i-1,j] + G[i,j-1]) - (G[i,j+1] + G[i+1,j])) / 2$$

... formula 75

$$Zk[i,j] = ((Z[i-2,j] + Z[i,j-2]) - (Z[i,j+2] + Z[i+2,j])) / 2$$

15 ... formula 76

 In case2,

$$Gk[i,j] = G[i,j-1] - G[i,j+1] \quad \dots \text{formula 77}$$

$$Zk[i,j] = Z[i,j-2] - Z[i,j+2] \quad \dots \text{formula 78}$$

 In case3,

20 $Gk[i,j] = ((G[i-1,j] + G[i,j+1]) - (G[i,j-1] + G[i+1,j])) / 2$

... formula 79

$$Zk[i,j] = ((Z[i-2,j] + Z[i,j+2]) - (Z[i,j-2] + Z[i+2,j])) / 2$$

... formula 80

 In case 4, same as an case 1

25 In case 5,

Gk[i,j]=1, Zk[i,j]=1

In case 6, same as an case 3

In case 7, same as an case 1

In case 8

5 Gk[i,j]=G[i-1,j]-G[i+1,j] ... formula 81

Zk[i,j]=Z[i-2,j]-Z[i+2,j] ... formula 82

In case 9, same as an case 3

Next, the interpolation processing unit 17 calculates the green color interpolation value G[i,j] as follows.

10 In case 1, G[i,j] = Gvk[i,j]

In case 2, G[i,j] = Gvk[i,j]

In case 3, G[i,j] = Gvk[i,j]

In case 4, G[i,j] = (Gvk[i,j] + Ghk[i,j])/2

In case 5, G[i,j] = (Gvk[i,j] + Ghk[i,j])/2

15 In case 6, G[i,j] = (Gvk[i,j] + Ghk[i,j])/2

In case 7, G[i,j] = Ghk[i,j]

In case 8, G[i,j] = Ghk[i,j]

In case 9, G[i,j] = Ghk[i,j], with

Gvk[i,j]=(G[i,j-1]+G[i,j+1])/2

20 +Gk[i,j]/Zk[i,j]·(2·Z[i,j]-Z[i,j-2]-Z[i,j+2])/4

... formula 83 and

Ghk[i,j]=(G[i-1,j]+G[i+1,j])/2

+Gk[i,j]/Zk[i,j]·(2·Z[i,j]-Z[i-2,j]-Z[i+2,j])/4

... formula 84.

25 In formulae 83 and 84, the first term represents the

"local average information of the green color component" which is equivalent to the primary term in formula 1 and formula 2. The second term is the "local curvature information based upon a color component matching the color component at the interpolation target pixel" multiplied by a weighting coefficient (a value indicating the correlation between the inclination $Gk[i,j]$ of the green color component and the inclination $Zk[i,j]$ of the red color component (or the blue color component): $Gk[i,j]/Zk[i,j]$), and is equivalent to the correctional term.

Namely, in the fourth embodiment, the local average information of the green color component is corrected by using the "local curvature information based upon a color component matching the color component at the interpolation target pixel" multiplied by the weighting coefficient.

Now, a problem that arises when calculating the correction value by simply adding the "local curvature information based upon a color component matching the color component at the interpolation target pixel" without being multiplied by the weighting coefficient to the "local average information of the green color component" is discussed.

For instance, when color information corresponding to

the green color component and color information corresponding to the red color component (or the blue color component) are provided as indicated by ● in FIG. 15 (when the values indicated by the color information corresponding to the green color component start to increase at a specific position and the values indicated by the color information corresponding to the red color component (or the blue color component) start to decrease at the same position), the "local curvature information based upon a color component matching the color component at the interpolation target pixel" indicates a positive value. Thus, in such a case, if the "local curvature information based upon a color component matching and the color component at the interpolation target pixel" is added to the "local average information of the green color component" without first multiplying it with the weighting coefficient, the "local average information of the green color component", which should be corrected along the negative direction, becomes corrected in the positive direction as indicated by \triangle in FIG. 15, resulting in an overshoot.

In other words, when color information corresponding to the green color component and the color information corresponding to the red color component (or the blue color component) change in opposite directions from a

specific position at a color boundary, an overshoot or an undershoot occurs if the correctional term is calculated simply by adding the "local curvature information based upon a color component matching the color component at the interpolation target pixel" to the "local average information of the green color component" without first multiplying the "local curvature information based upon a color component matching the color component at the interpolation target pixel" by the weighting coefficient.

In the embodiment, if color information corresponding to the green color component and color information corresponding to the red color component (or the blue color component) are provided as indicated by ● in FIG. 15, the sign of the inclination $Gk[i,j]$ corresponding to the green color component and the sign of the inclination $Zk[i,j]$ corresponding to the red color component (or the blue color component) are opposite from each other resulting in the weighting coefficient being a negative value. Thus, the "local average information of the green color component" is corrected in the desired direction as indicated by □ in FIG. 15, preventing an overshoot or an undershoot from occurring.

Consequently, the occurrence of color artifacts attributable to over correction at a color boundary is reduced in the fourth embodiment.

It is to be noted that while no restrictions are imposed with regard to the value of the weighting coefficient in the fourth embodiment, restrictions may be imposed to set the value of the weighting coefficient
5 within a specific range to ensure that the correctional term does not become too large.

For instance, the range for the weighting coefficient may be set; $|G_k[i,j]/Z_k[i,j]| \leq 5$.

(Fifth Embodiment)

10 The following is an explanation of the operation achieved in the fifth embodiment.

It is to be noted that since the RB interpolation processing in the fifth embodiment is performed as in the first embodiment, its explanation is omitted. However, in
15 the fifth embodiment, color differences containing the red color component are interpolated for some of the pixels at which color information corresponding to the green color component is present through formula 51 and color differences containing the red color component are
20 interpolated for the remaining pixels at which color information corresponding to the green color component is present and for pixels at which color information corresponding to the blue color component is present through formula 52, as in the third embodiment.

25 Now, the G interpolation processing is explained.

In the fifth embodiment, in which the closest pixels at which color information corresponding to the green color component is present are set along the horizontal direction to a pixel to undergo the G interpolation processing as shown in FIGS. 3A and 3B, interpolation processing is achieved in the simplest manner by using the color information at the pixels set along the horizontal direction. Accordingly, the green color interpolation value $G[i,j]$ is calculated in the fifth embodiment as in case 8 in the fourth embodiment.

Namely, the interpolation processing unit 17 calculates the green color interpolation value $G[i,j]$ through formula 85.

$$G[i,j] = (G[i-1,j] + G[i+1,j]) / 2$$

$$+ G_k[i,j] / Z_k[i,j] \cdot (2 \cdot Z[i,j] - Z[i-2,j] - Z[i+2,j]) / 4$$

... formula 85, with

$$G_k[i,j] = G[i-1,j] - G[i+1,j] \quad \dots \text{formula 81 and}$$

$$Z_k[i,j] = Z[i-2,j] - Z[i+2,j] \quad \dots \text{formula 82.}$$

As indicated above, in the fifth embodiment, the local average information of the green color component is corrected by using the "local curvature information based upon a color component matching the color component at the interpolation target pixel" multiplied by the weighting coefficient (a value representing the correlation between the inclination $G_k[i,j]$ corresponding to the green color

component and the inclination $Zk[i,j]$ corresponding to the red color component (or the blue color component):

$Gk[i,j]/Zk[i,j]$) as in the fourth embodiment. As a result, the occurrence of color artifacts attributable to over

5 correction at a color boundary can be reduced through the fifth embodiment.

It is to be noted that while an explanation is given above in reference to the embodiments on an example in which the color difference is used as a hue in the G

10 interpolation processing and the RB interpolation processing, G interpolation processing and RB interpolation processing can be achieved in a similar manner by using a color ratio or the like as a hue instead of a color difference.

15 While an explanation is given above in reference to the individual embodiments on an example in which the curvature information based upon each color component is calculated through quadratic differentiation, the present invention is not limited to this example, and curvature
20 information may be obtained through differentiation of a higher order. In other words, any method may be adopted as long as the degree of change in the rate of change occurring in each color component is ascertained.

(Sixth Embodiment)

25 The following is an explanation of the operation

achieved in the sixth embodiment.

FIG. 16 is a functional block diagram representing the sixth embodiment. In FIG. 16, the same reference numbers are assigned to components achieving identical functions to those in the functional block diagram in FIG. 1 to preclude the necessity for repeated explanation of their structures.

The structure of an electronic camera 20 shown in FIG. 16 differs from that of the electronic camera 10 in FIG. 1 in that a control unit 21 and an image processing unit 22 in FIG. 16 replace the control unit 11 and the image processing unit 15 in FIG. 1, with an interface unit 23 in FIG. 16 provided as an additional component.

In addition, in FIG. 16, a personal computer 30 is provided with a CPU 31, an interface unit 32, a hard disk 33, a memory 34, a CD-ROM drive device 35 and a communication interface unit 36 with the CPU 31 connected to the interface unit 32, the hard disk 33, the memory 34, the CD-ROM drive device 35 and the communication interface unit 36 via a bus.

It is to be noted that an interpolation processing program (an interpolation processing program for executing interpolation processing similar to that implemented at the interpolation processing unit 17 in the various embodiments explained earlier) recorded at a recording

medium such as a CD-ROM 37 is pre-installed at the personal computer 30 via the CD-ROM drive device 35. In other words, the interpolation processing program is stored at the hard disk 33 in an execution-ready state.

5 The following is an explanation of the operation achieved in the sixth embodiment, given in reference to FIG. 16.

First, image data generated as in the electronic camera 10 shown in FIG. 1 are provided to the image processing unit 22 in the electronic camera 20. The image data undergo image processing (e.g., gradation conversion processing) other than interpolation processing at the image processing unit 22, and the image data having undergone the image processing are then recorded at the recording unit 16 in an image file format.

This image file is provided to the personal computer 30 via the interface unit 23.

Upon obtaining the image file via the interface unit 32, the CPU 31 in the personal computer 30 executes the interpolation processing program. The image data with resolutions corresponding to the individual color components enhanced through the interpolation processing then undergo image compression and the like as necessary, are recorded at the hard disk 33 or the like and are finally output as data in a colorimetric system

corresponding to the type of individual device connected,
such as a display or a printer.

Namely, interpolation processing similar to that
achieved in the embodiments explained earlier is
5 implemented on the personal computer 30 in the sixth
embodiment.

While an explanation is given in reference to the
sixth embodiment on an example in which the interpolation
processing program is provided through a recording medium
10 such as the CD-ROM 37, the recording medium that may be
used is not limited to a CD-ROM and any of various types
of recording media including magnetic tape and a DVD may
be used instead.

In addition, programs may be provided via a
15 transmission medium such as a communication line 38, a
typical example of which is the Internet. In other words,
the programs which are first converted to signals on a
carrier wave that carries a transmission medium may be
transmitted. The personal computer 30 shown in FIG. 16
20 has such a function as well.

The personal computer 30 is provided with the
communication interface unit 36 that connects with the
communication line 38. A server computer 39, which
provides the interpolation processing program, has the
25 interpolation processing program stored at a recording

medium such as an internal hard disk. The communication line 38 may be a communication line for connection with the Internet or for a personal computer communication or it may be a dedicated communication line 38. The

5 communication line 38 may be a telephone line or a wireless telephone line for a mobile telephone or the like.

It is to be noted that the interpolation processing program according to the present invention that is executed within the electronic camera 10 in FIG. 1 is normally installed in a ROM (not shown) or the like at the time of camera production. However, the ROM in which the interpolation processing program is installed may be an overwritable ROM, and the electronic camera may be then connected to a computer assuming a structure similar to that shown in FIG. 16, to allow an upgrade program to be provided from a recording medium such as a CD-ROM via the computer. Furthermore, an upgrade program may be obtained via the Internet or the like as described earlier.